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ABOUT THE COVER

Improving and maintaining rangelands for more efficient grazing of sheep and cattle is a major concern for ranchers in Utah. A totally new approach, short-duration grazing, not only enhances range condition, but it also increases livestock productivity.

WEATHER AND RANGE MANAGEMENT

E. A. RICHARDSON, T. F. GLOVER, and B. A. HAWS

THE PRODUCTS OF UTAH'S RANGES CONTRIBUTE MORE to the economy of the state than almost any other form of agriculture despite being unusually subject to the vagaries of the weather. Drought, winter blizzards, desiccating summer heat, and extreme cold can all exert a devastating impact on range production. Such factors are therefore critical in designing management practices to optimize range production. Unfortunately, those same factors defy control by mere humans.

Although they can't be controlled, statistical analysis and computer modeling techniques can be used to develop probabilities of their occurrence and to estimate their impact on production. With predictability, management practices could be improved. Toward that end, researchers at USU have been working on several projects for a number of years.[1]

From these efforts have come both answers and further questions. For example, the Range Condition Model has allowed us to predict better than normal forage production for all of Utah's ranges in 1983 unless summer precipitation drops to less than 50 percent of normal and/or temperatures are abnormally cold. Using other models and equations, we have developed data that range managers can use to gain economically practicable control over the black grass bug. Models of crested wheatgrass growth and development have given us insights into how this grass can be managed for productivity.

Answers to additional questions continue to be sought—on the ranges, in the greenhouse and at computer terminals. Some of the processes that were and are being used can be described as follows:

The Range Condition Model

In the study sponsored by the Bureau of Reclamation, projections of range productivity were needed as inputs to the range utilization decision process and various economic evaluation models for each of Utah's climate divisions. Various alternative functional forms that represented growth relationships were tested. Data describing range forage productivity were taken from the Range Condition Index data series published by the U.S. Department of Agriculture. Data on weather variations were obtained from the Palmer Index Series developed by Wayne Palmer of the National Weather Service. The response models developed during the study followed, in general, the growth response modeling procedures found in recent scientific literature on growth systems. The best index tested was found to be a modification of the Palmer Drought Index which is now being calculated each month for all of the climate divisions in the nation.

After considerable manipulation of equations, we found that 60 to 85 percent of the variation in range conditions could be explained by variation in the Palmer Index for Utah's climatological regions, and from 41 to 91 percent of the variation was explained by equations estimated for states west of the Mississippi. In general, the equations tended to better represent range condition-weather relationships in the northern and more

[1] These research projects were sponsored by the Bureau of Reclamation, the Bureau of Land Management, and the Four Corners Commission (now discontinued).

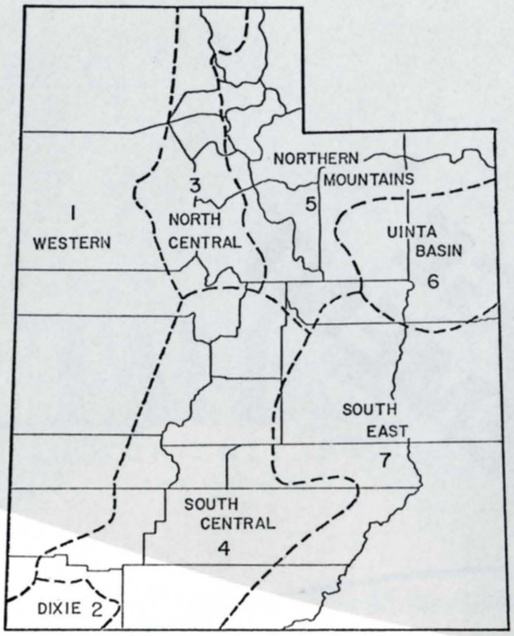


FIGURE 1. Climate Division Map.

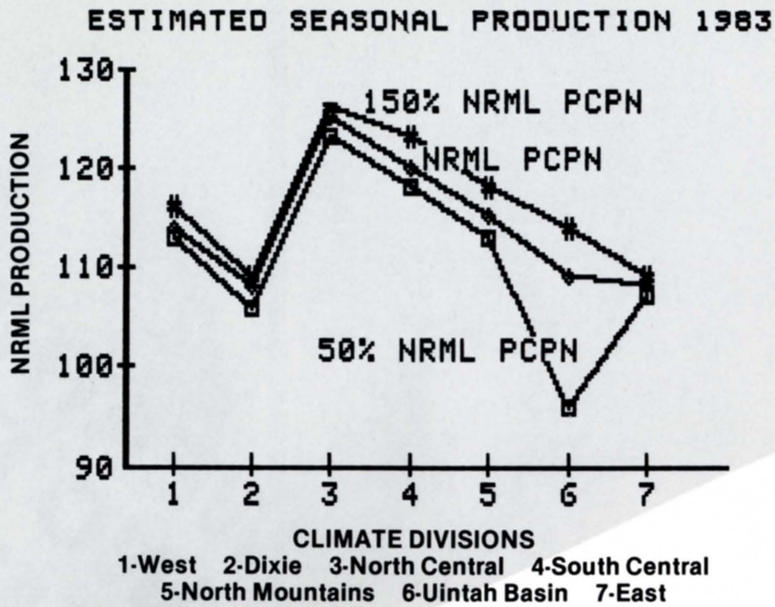


FIGURE 2. Estimated seasonal production in Utah's seven climate divisions.

arid states. The estimated coefficients for the equation for each of the climate divisions in Utah are given in Table 1.

Range conditions for Utah's 1983 growing season have been projected using these equations in conjunction with the latest available weather information through the end of April 1983. The projections were made for each of the climate divisions in Utah. Alternative assumptions were made for 150 percent of normal rainfall during the remainder of the growing season, normal rainfall, and 50 percent of normal (Figure 1). As indicated by the graphs, range forage production should be above normal in all areas of the state if precipitation continues at normal or higher during the remainder of the growing season. Even if the precipitation drops to only 50 percent of normal, production should exceed normal in 4 of the 7 divisions of the state.

Our current methods of estimating production is necessarily gross. The Bureau of Land Management, however, is supporting a research program to try to produce more accurate estimates on an individual species basis.

The Asymmetric Curvilinear Model (ASYMCUR)

For well over a hundred years, scientists have recognized that two of the major factors affecting the growth and development of living organisms are temperature and moisture. Several mathematical models involving one or both of these environmental factors have been developed, but the majority of these are quite site specific and can be applied with any degree of accuracy in only a limited area. Most of the temperature-related models have assumed a linear relationship between temperature and rate of activity and/or growth and development. More recently, it has been recognized that the growth curve has a curvilinear shape, similar to that shown in Figure 2.

In general, five cardinal temperatures are important to define the growth and survival of living organisms. First is the lower lethal temperature (T11), defined as the temperature below which an organism is damaged or killed. Second is the base temperature (Tb), below which little or no growth will occur. Third is the optimum temperature (Tu), at which the rate of growth or development is maximized. Fourth is the critical temperature (Tc), the temperature above which little or now growth or development will occur. Fifth is the upper lethal temperature (Tul), the temperature above which the organism is severely damaged or dies. In Figure 2, (Tb) corresponds to the temperature at point A, (Tu) the temperature at point B, and (Tc) the temperature at point C.

More careful analysis of the available data enabled us to develop equations which better fit the growth pattern of organisms than that represented by Figure 2. This improved relationship has been given the name (ASYMCUR) and includes the potential for the consideration of moisture stress as it operates under range conditions (Figure 3).

Estimating the Value of the Moisture Stress Factor (F)

The method of estimating the Moisture Stress Factor (F) is illustrated in Figure 3. The assumption is made that a plant does not undergo appreciable stress until the soil moisture drops to a certain percent of field capacity. The value of F is assumed to be 1 between field capacity and that percent. As the soil moisture drops below that critical percentage point (25 percent in the case of many range species), the value of F drops gradually to a critical value (generally between .50 and .25) again depending upon the plant species. For most range species, a value of .25 at the wilting point was assumed.

Applying the soil moisture stress factor, F, reduces the amplitude of the growth curve. In other words, it lessens the influence of the accumulation of

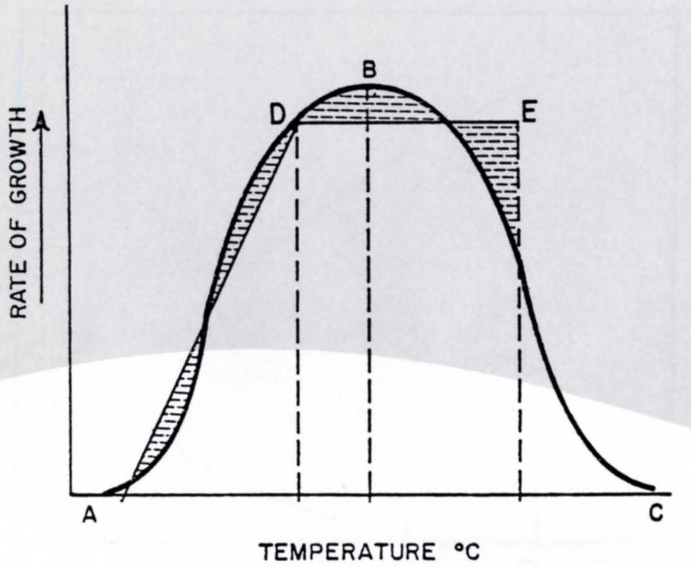


FIGURE 3. Linear approximation of development curve as related to temperature environment.

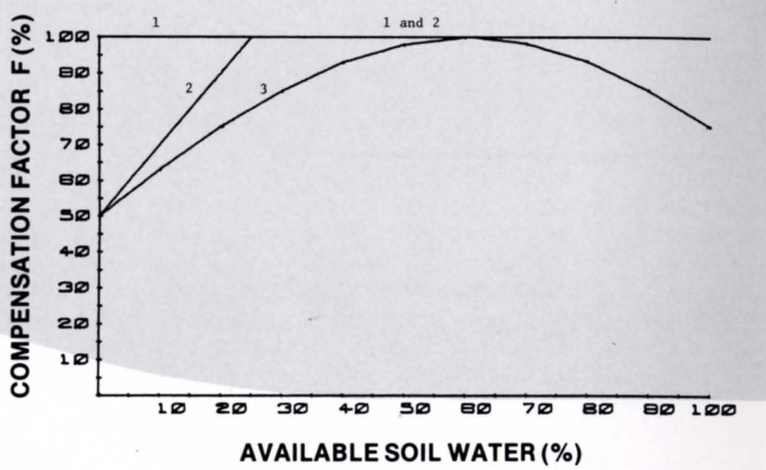


FIGURE 4. Relationships between the soil moisture compensation factor 'F' and soil moisture used to adjust energy accumulations.

Growing Degree Hours (GDH) on the production and growth of a plant species.

This kind of information was then applied to the development of both plants and insects on the range. Two examples will be given.

The *Labops hesperius* Model

The original model for *Labops hesperius* (Black Grass Bug) described in the final report to the Four Corners Commission in 1978 consisted of two parts: (1) The Chill Unit Model predicted the time of beginning egg development in the spring and (2) the Growing Degree Hour model predicted the development of the egg and insect following completion of the chilling period.

(1) The Chill Unit Mode. *Labops* produces only one generation per year. The eggs do not mature during the same growing season due to a mechanism that prevents development beyond a certain stage until a period of exposure to cool winter temperatures has been completed. Fuxa and Kamm (1976) reported that eggs brought in from the range about the first of September required a minimum of 60 days exposure to temperatures of 3°C or 6°C before they would hatch. These temperatures fall on the Chill Unit Curve (CU) developed by Richardson et al. (1974) (Figure 4) to explain the winter cold requirements of fruit trees. (A 'Chill Unit' is defined as an exposure of one hour at 6 degrees Celcius or its equivalent as determined from the curve in Figure 3.) A preliminary analysis of available data indicated a chill requirement of 1300 Chill Units to meet the dormancy requirements of *Labops* eggs.

TABLE 1. Regression Constants for Range Condition Equation

Division	Constant	B1	B2	R^2	D-W
Western	-1.6327	-.31785	-----	.852	1.79
Dixie	-1.509	-.27727	.04281	.626	2.22
North Central	-1.204	-.25318	-----	.737	1.64
South Central	-1.1843	-.26513	-----	.785	1.33
North Mountains	-1.1908	-.1796	-----	.605	1.46
Uinta Basin	-1.4321	-.27004	-----	.747	1.39
South East	-1.7657	-.37448	.04031	.788	1.81
State of Utah	-1.477	-.2563	.02917	.904	1.58

A graduate student, Eric Coombs, has recently verified the calculations reported in the Four Corners Final Report (1978). The CU requirements for eggs newly collected in the field before any appreciable winter chilling had taken place ranged between about 1250 and 1300 CU. With eggs collected later in the season or in cooler areas, some accumulation of Chill Units may have taken place and the laboratory accumulations may be less than the 1300 CU indicated.

(2) The Growing Degree Hour Model. Once the chill requirements of the eggs have been met, any temperatures above 4 degrees Celcius will induce development. Our growth chamber studies indicate that the cardinal temperatures for *Labops* are as shown in Table 2.

TABLE 2. Cardinal Temperatures for *Labops hesperius*

Lower Lethal Temperature (T11)	about 0°C
Base Temperature (Tb)	4°C
Optimum Temperature (Tu)	26°C
Critical Temperature (Tc)	36°C
Upper Lethal Temperature (Tul)	Not determined

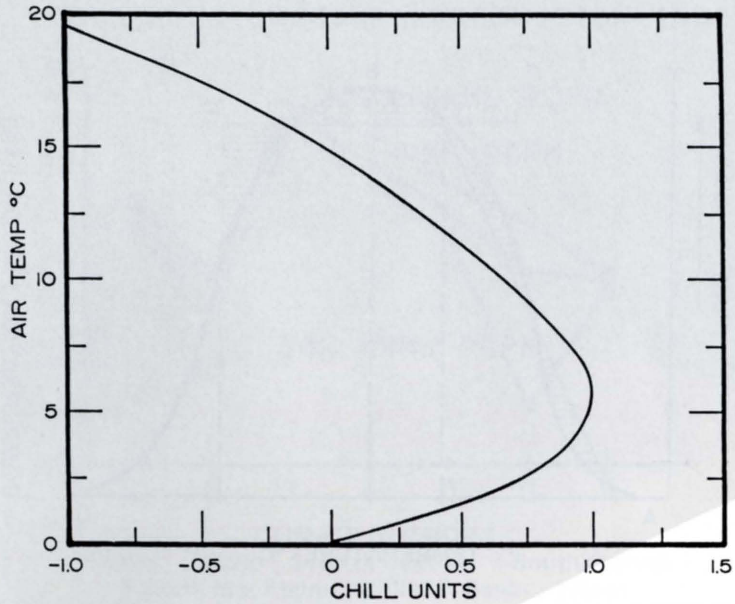


FIGURE 5. Curve relating chill units to Celsius temperature.

When these temperatures were used in certain equations and related to the insect phenology obtained by Coombs, the GDH-Phenology relationships were as shown in Table 3.

TABLE 3. Phenology Constants for *Labops hesperius*

Stage	CU or GDH Accumulation
Chill Unit Requirement	1250 or 1300 CU
Hatch	4,800 GHD C
1st Instar	5,560 GHD C
2nd Instar	6,500 GHD C
3rd Instar	7,940 GHD C
4th Instar	9,426 GHD C
5th Instar	11,357 GHD C
Adult	13,666 GHD C
Mature adult	15,257 GDH C

These GHD and CU requirements were determined in the laboratory. In relating GDH as calculated from temperatures measured in the instrument shelter in the field to the same stages of development, it is necessary to recognize that canopy temperatures where the eggs have been deposited will be warmed in the daytime and cooled at night. Currently available information indicates that subtracting about 3 degrees C from the minimum shelter temperature and adding about 5 degrees C to the maximum shelter temperature for each day will result in usable GHD predictive values for most of Utah's rangelands. However, further work needs to be done in relating shelter temperatures to canopy temperatures, especially before appreciable growth of the plants has begun.

Managers can use the *Labops* model to predict the stages of development of the insects. They can thereby increase the effectiveness and less the costs of control measures on the range. In the past, the timing has depended upon expensive field observations.

The Crested Wheatgrass Models

Grasses and other range species upon which insects feed obviously respond to the same environmental conditions as do the insects. It was therefore decided that models to predict the development of certain key grass species would promote our understanding of the growth and development of the insects. Because we could not develop models for all related species, we concentrated our efforts on Crested Wheatgrass, which is one of the major grasses used in reseeding ranges in the western United States.

Analysis of several years of data obtained from studies supported by the Bureau of Land Management in the Vernal and Price areas of Utah indicated that the best fit cardinal temperatures for Crested Wheatgrass (*Agropyron cristatum*) were Tb = 4°C, Tu = 25°C, and Tc = 36°C.

The development of the Crested Wheatgrass seed stem is triggered by daylength. The daylength trigger is not effective until the plant has accumulated about 2000 growing degree hours (i.e., the plant is between its 3- and 4-leaf stage). The final height of the seed stem is determined by the daylength at the time the plant reaches this phenological stage of development. Established plants on the range more or less follow the model indicated. In growth chambers and greenhouse studies, the height of the seed stems will vary depending upon the daylength observed at this stage of development. Further work needs to be done in establishing an exact daylength relationship.

To test our Crested Wheatgrass models, we use the records of one year of observations taken in Juab County, Utah, at the Tintic Research Site of the USU Range Science Department. No other information is currently available.

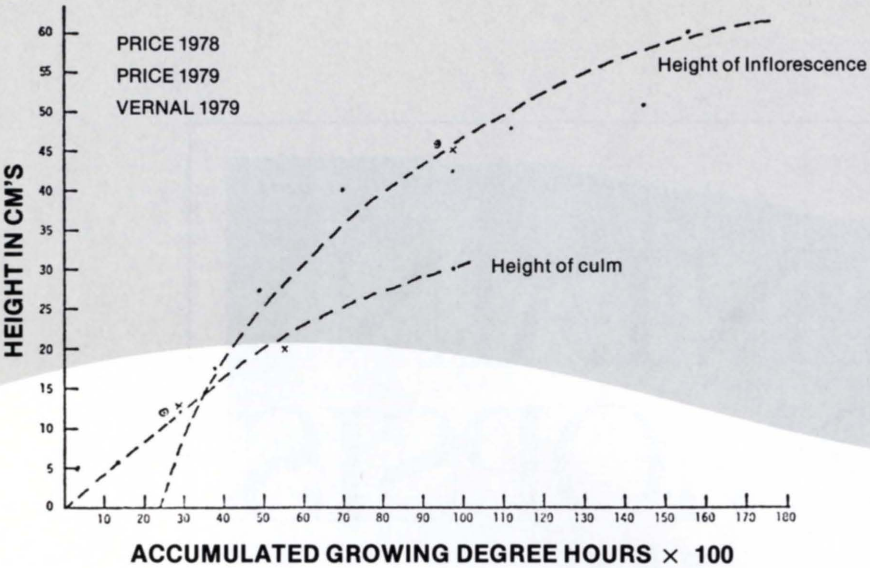


FIGURE 6. *Agropyron cristatum* (Crested Wheatgrass) AGCR.

Range modeling shows promise in controlling black grass bug and increasing forage.

Predicted and observed dates of occurrence of selected phenological stages and heights were compared in Table 4. The GDH constants for these stages had been determined from the Vernal and Price data discussed earlier and were used to predict the dates of occurrence at Tintic.

As Table 4 shows, the average difference between the predicted and observed dates of the phenological stages ranged between −6 and +4 days. Considering that no actual soil moisture information was available, these are fairly accurate predictions.

Through the continued support of the BLM, 10 weather stations have been installed on major ranges in Utah. The data collected every day will include maximum and minimum temperatures, average soil temperature at the 4-inch and 20-inch depths, soil moisture information at two depths, solar radiation accumulation, and precipitation measurements. Phenology, height, and production data will also be obtained for selected key species during the coming growing season.

These data will be used to further refine the growth and production model of the grasses and insect species just described and to develop models for several other key range species.

TABLE 4. Comparison of Predicted and Observed Dates of Occurrence of Selected Phenological Stages and Heights of Crested Wheatgrass at the Tintic Research Site, 1980.

Phenology stage	Predicted date	Observed date	Height of culm	Predicted date	Observed date
3 Leaf	232	230	10 cm	240	233
4 Leaf	246	250	15 cm	258	249
5 Leaf	273	279	20 cm	273	267
Boot	291	292	25 cm	286	281
Full flower	310	306	30 cm	300	290
Seed ripe	341	347			

ABOUT THE AUTHORS

E. Arlo Richardson is the Utah State Climatologist, Utah Department of Agriculture at Utah State University. He holds BS and MS Degrees from Brigham Young University and a Certificate of Competence in Meteorology, University of Chicago.

B. Austin Haws is a professor of Biology and Entomology at USU. He received his PhD at Iowa State University. He is currently studying beneficial and injurious insects of rangeland plants, forbs and shrubs.

T. F. Glover is professor of economics, PhD agricultural. He received his PhD in Agricultural Economics from Purdue. He is currently working on production and policy economics.

MOUNTAIN THERMOPSIS TOXICITY IN CATTLE

R. L. CHASE and R. F. KEELER

MOUNTAIN THERMOPSIS (*Thermopsis montana*), known as poison bean plant in many areas and false lupine in others, is suspected by some ranchers to be poisonous to cattle. Others have lived with it for a long time and do not consider it a threat.

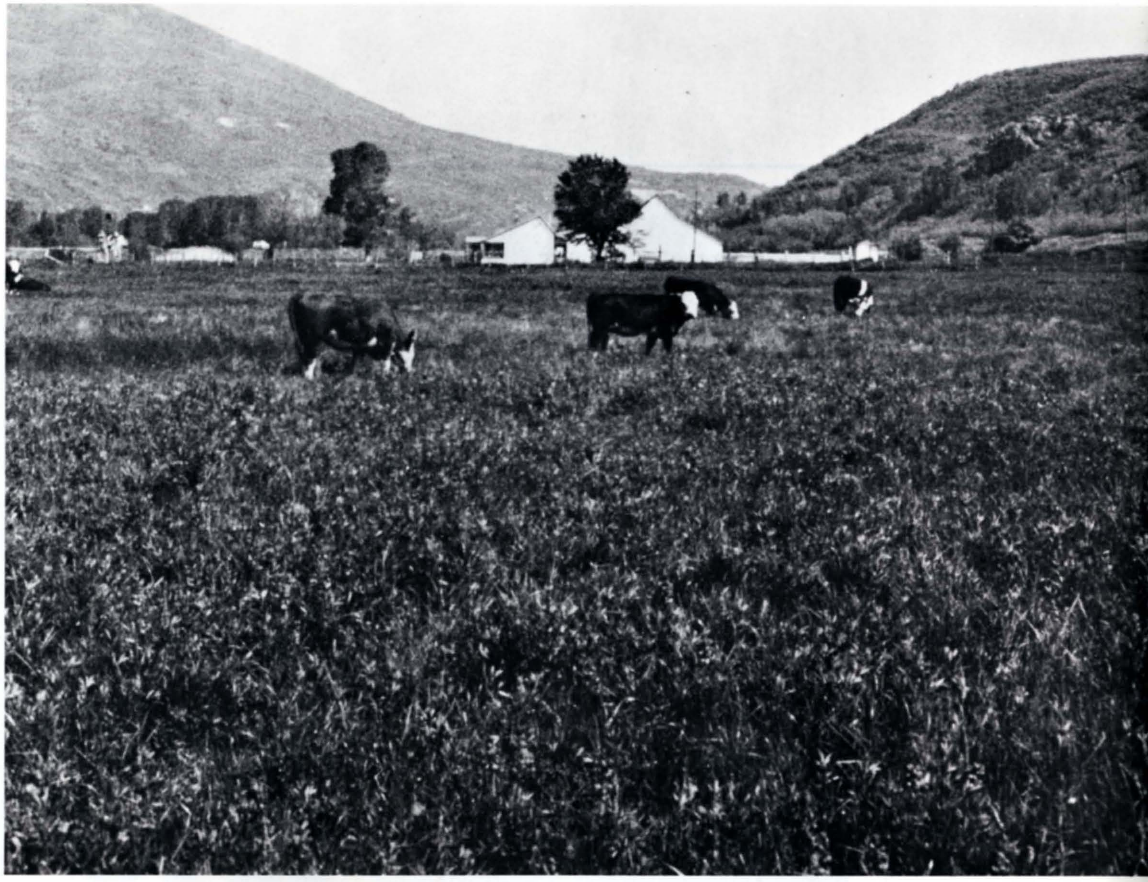
Thermopsis is an erect, perennial legume that grows one to two feet high and has creeping rootstocks. There are three leaflets per leaf, the bright yellow flowers are borne terminally in moderately dense clusters, and the pods are straight and erect. The plant prefers rich, moist meadows or streambanks. In Utah, it is found in the higher mountain valleys where abundant moisture is present. The counties with moderate to heavy infestations include: Rich, Wasatch, Summit, Wayne, Piute, and Garfield. Another Thermopsis species found in the state is *Thermopsis divaricarpa,* but it appears not to be as plentiful as *Thermopsis montana*. The seed pods of *T. divaricarpa* are curved instead of straight. This plant can also tolerate dryer conditions than *T. montana*. Although not much is known about *T. divaricarpa,* it likely has toxic properties similar to those of *T. montana*.

Thermopsis montana has not generally been recognized as being toxic in cattle. It is not even mentioned in Kingsbury's

PHOTOS

Mountain stream lined with Thermopsis.

Thermopsis is a legume with bright yellow flowers. The pods grow straight and erect emerging in July and maturing in late summer. Just before the pods burst and the seeds fall to the ground, the plant is most toxic to cattle.



Severe symptoms include lack of appetite, humped up, swollen eyelids, depression, and drawn up flanks.

book, *Poisonous Plants of the U.S. and Canada*, although another species, *Thermopsis rhombifolia*, is mentioned as being suspected of causing losses of cattle and horses. Thermopsis is mentioned in *Stock Poisoning Plants of Montana*, a USDA publication which notes that thermopsis has even been regarded by stockmen as good hay if cut young. A case was also mentioned, however, in which 100 cattle died and thermopsis was highly suspected as being the cause of death.

In the summer of 1980, John Barnard, county agent in Rich County, reported the loss of several cows near a stream in an area heavily infested with mountain thermopsis. An investigation revealed that forage was extremely limited with the exception of the thermopsis, which at the time had flowered and was bearing pods nearly full of mature seeds. Although evidence was not conclusive, it was postulated that several cows had taken a liking to the seed pods, since these had been cropped off to a large degree. This incident rekindled our interest in continuing our studies of the toxicity of thermopsis.

The necessary feeding studies were conducted at the USDA Poisonous Plant Research Lab at Utah State University. Plant materials for feeding trials were collected from Piute County near Burrville (1977), around Elko, Nevada (1979), and in Rich County near Randolph (1981 and 1982). In most trials, cattle weighing an average of 1,200 lbs. were fed sun-dried plant material for approximately 30 days. The thermopsis was made into a slurry with water and administered by passing a tube through the mouth into the rumen. The material was then pumped into the rumen through the tube.

The plants from Burrville in Piute County were in full seed when collected on August 15, 1977, and this plant material was fed to six cows. About 300 grams per day produced severe symptoms.

The plants collected from near Elko were fed to seven cows. About 275 grams per day produced severe symptoms.

In a 1981 feeding study, plant material was used that was collected in Rich County on August 6, 1981. The seed pods had fallen, so very few seeds remained in the material to be fed. About 400 grams per day were required to produce severe symptoms in two cows. These symptoms included: lack of appetite, humped up, swollen eyelids, depression, and drawn up in the flanks. One thousand grams per day for five days put one cow down, and she was unable to get up for two weeks.

The most recent feeding study involved two cows with one fed 300 grams of dried material for three days. At that time she went down. She was unable to stand for the next 9 days. The plant material had been collected in Rich County on July 20, 1982, and was in seed at the time of collection. About 120 to 150 grams per day produced

Proper management of range and pasture land is one way to prevent losses from Thermopsis.

As long as there is adequate desirable vegetation, cattle will not usually graze Thermopsis.

Thermopsis is easily identified by the bright yellow flowers. Also, the leaves grow in groups of three. It is often found near mountain streams as it thrives on an abundance of moisture.

severe symptoms in the other cow. She was fed this dose for the remainder of the 30-day period. Symptoms from that dose included depression, swollen eyelids, drawn up in the flanks, and a rough hair coat.

Based on observed toxic signs, we can speculate that doses only slightly higher than those fed in these trials would have been lethal. Thus, 500 grams or so of highly toxic thermopsis could be enough to kill an average-size cow. On the other hand, double that amount from less toxic plant parts or growth stages might not be lethal.

The two principal alkaloids that are responsible for the toxicity of thermopsis are anagyrine and thermopsine. The concentrations of these alkaloids vary depending upon the growth stage of the plant. Young plants have relatively high levels of alkaloids. The alkaloid levels decrease until seed set, at which time there is a dramatic increase because the seeds themselves are high in alkaloid content. Thus, when the seeds fall, so does the toxic alkaloid content in the remaining above-ground parts of the plant.

Our evidence indicates that thermopsis plants vary in alkaloid content from area to area. The plants collected near Elko, Nevada, are believed to differ chemically from the plants collected in Utah.

From a practical standpoint, young plants are not too hazardous because cattle are less likely to eat thermopsis while other good forage is available in abundance, as it is early in the year. Nor is thermopsis likely to be hazardous in the flowering stage. If the time when the plants set seed coincides with the lack of desirable vegetation on a particular grazing area, however, the plant could then be hazardous because cattle will likely consume it along with its highly toxic seeds.

Proper management of range and pasture lands is one way to prevent losses from thermopsis. With access to sufficient, good quality forage, cattle are less likely to consume excessive amounts of thermopsis.

It is highly desirable to keep the plants from spreading. Applications of 2,4-D plus dicamba when the plant is in its bud-to-early-flower-stage has been found to be effective by the Rich County Weed Department. One pint dicamba (Banvel) plus 3 pts 2,4-D should give control. Retreatment may be necessary.

ABOUT THE AUTHORS

Rick Chase, Extension Weed Specialist, has worked as an extension agent and has done weed research in El Salvador. Dr. Chase, a member of the Plant Science Department, heads up the State Weed Committee and is responsible for statewide educational programs in weed control. His long-range goal is to prevent new and invading weeds.

Richard F. Keeler is a research chemist with the USDA Poisonous Plant Research Laboratory at USU. He received his PhD in Biochemistry from Ohio University. His work is in toxic and teratogenic compounds from poisonous plants.

J. C. MALECHEK and D. D. DWYER

SHORT-DURATION GRAZING

DOUBLES YOUR LIVESTOCK?

FIGURE 1a. Physical design of the 10-paddock, 210-acre grazing cell for the proposed short-duration grazing experiment at the Tintic pastures in Juab County. The radial arrangement of paddocks where cattle water in, and move through, a common central area is thought to minimize the animal stress commonly associated with traditional rotational grazing schemes. It also minimizes expense for water development.

FIGURE 1b. Diagram of the cell center. Animals water in the narrow corridor and move through it when rotating from pasture to pasture. Theoretically, the confined area available in the corridor induces animals to quickly return to the pasture after watering instead of "camping" near the water trough as is the usual tendency. The area in the center can be used for working corrals, weighing scales or storage.

FIGURE 2. New Zealand-type electrical fence utilizing smooth steel wire and drivable fiberglass posts. Fence is energized to about 5000 volts by a solid-state energizer using a 12-V auto battery. A solar-cell battery charger can be used to maintain the electrical charge of the battery.

FIGURE 3. New Zealand electrical fence on a New Mexico project. The stationwagon is passing through a "gate" device that simply lifts the whole fence, allowing passage of vehicles or livestock. Major advantages of this fencing include effective control of wild range cattle, relatively low cost (as little as $600 to $1000 per mile), ease of construction, and minimal visual impact, which is a major consideration on public lands.

FIGURE 4. Typical behavior of cattle on rangeland managed by conventional, extensive grazing practices. Animals over-utilize the gentle terrain and stream-side areas while letting forage on steep slopes and distant areas go ungrazed.

FIGURE 5. In Utah, seeded stands of crested wheatgrass like this one are highly productive and provide critical spring-time forage to the livestock industry. Intensified management systems such as S-DG may, however, make them even more effectively useful.

FIGURE 6. Side-by-side illustration of how properly timed grazing can maintain crested wheatgrass in a physiologically young (highly nutritious and palatable) condition. Pasture on the right was not grazed, while the one on the left was grazed early in growing season. Photo was taken in September when crested wheatgrass is normally dry and mature.

UTAH CATTLE RANCHERS ARE MIRED IN ECONOMIC TROUBLES. Their costs of production (including capital investments in land, equipment, and improvements) steadily rise, while prices paid for their products (cattle) remain the same.

One way to greatly reduce this squeeze is to improve the productivity of the land, making each acre yield more pounds of salable beef. As few as ten years ago, this could be done by so-called "range improvement" projects such as spraying sagebrush and planting desirable forage grasses. Today, however, high costs make such measures impractical unless heavily subsidized by government.

Better grazing management (e.g., specialized grazing systems) has often been heralded by professional range managers as an alternative to expensive range improvement projects. Their proponents claim that these grazing systems allow ranges to improve naturally through secondary plant succession and thereby increase the grazing capacity of the land.

FIGURE 1a

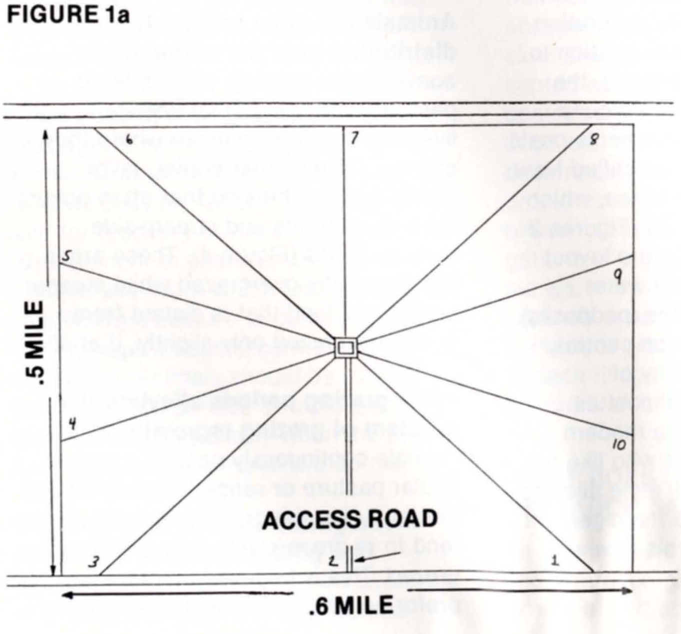
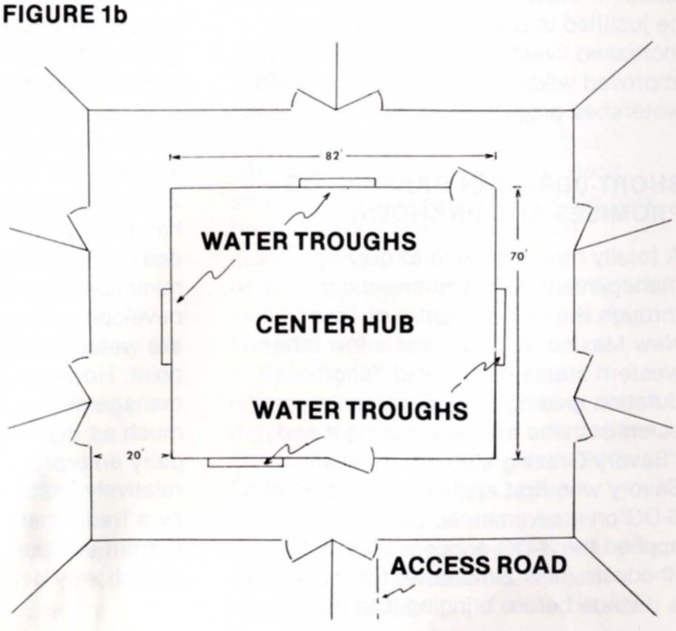


FIGURE 1b



A totally new approach to grazing management, short-duration grazing, may improve western range productivity.

The reluctance of private ranchers to undertake such grazing practices has had range managers wringing their hands and wondering which of several possible reasons should be blamed. In many cases, it could be the expenses. The proposed systems usually entail major fence construction and development of livestock water. In addition, the systems often require that animal numbers be reduced, to insure that range recovery will begin. Unfortunately, that reduction also tightens the economic squeeze that the rancher is trying to escape.

Another major problem for ranchers is the time it takes for their ranges to recover in arid regions such as Utah. Any major investment these ranchers might make in a specialized grazing system may not begin to pay off for ten or more years. Payments on loans, however, come due immediately.

Because of these short comings, specialized grazing systems have not found wide application except on public lands. In those situations, the costs can be justified in benefits that go beyond increased livestock production such as improved wildlife habitat and increased watershed protection.

SHORT-DURATION GRAZING: ITS PROMISES AND UNKNOWNS

A totally new approach to grazing management has been sweeping through the range country of Texas, New Mexico, Arizona, and a few other western states. It is called "short-duration grazing" (S-DG) by range scientists who are researching it and "Savory Grazing Method" by Alan Savory who first applied his version of S-DG on a commercial basis. Savory applied the S-DG concept in his native Rhodesia (now Zimbabwe) for more than a decade before bringing it to the Southwest United States in the late 1970s. He now operates a private ranch consulting firm in New Mexico.

Fundamentally, this new grazing management approach concentrates animals into one large herd that is rotated rapidly through a series of pastures (paddocks), which are usually arranged in a radial or "wagon-wheel" pattern (Figure 1a and b). Several advantages are claimed over continuous, season-long grazing in which animals are scattered over an extensive range. The point that most emphatically *seizes* the private rancher's attention, however, is the promise of an almost immediate *increase* in carrying capacity. Increases as large as a doubling of the stocking rates recommended by the USDA Soil Conservation Service have been implemented. Livestock producers, accustomed to hearing that cow numbers must be reduced if the ranges are to improve, find this to be both a startling and a captivating idea.

As always, however, there is a catch.

Although the initial capital investment necessary to undertake short-duration grazing is relatively small in relation to the potential increase in returns, the managerial commitment is profound. Fencing and capital improvements costs are kept low by using the so-called New Zealand type of electrical fence, which has proved its effectiveness (Figures 2 and 3). Also, the radial-pasture layout minimizes the necessity for water development as all pastures (paddocks) are watered from a common central point. However, the intensity of management required is almost as much as that required for a modern dairy enterprise. Ranchers who like the relatively unstructured life style allowed by a traditional, extensive management system are likely to find this new approach very demanding.

HOW MIGHT IT WORK?

How can ranges sustain or even improve their productivity when animal numbers are increased? Few data-based answers are available, but applications on a practical management scale indicate considerable promise for the S-DG approach. Preliminary research, primarily in Texas (see Heitschmidt et al. 1982), seems to support this.

In theory, the system works as follows:

Aggregated livestock utilize a larger proportion of the plants on the range. Under conventional grazing, and even under such improved practices as rest-rotation grazing, only a small proportion of the forage plants on a range support most of the grazing use. Many of the grass plants are never grazed and quickly grow to maturity and set seed. Once seed stalks are in place, the grass plants' palatability and nutritive value are greatly reduced. Grazing animals tend to avoid such plants.

Animals are more uniformly distributed over the range. Under conventional grazing, with its large pastures and low animal density, livestock are free to graze where they choose. Cattle, in particular, favor gentle terrain, the kind that often occurs in valley bottoms and stream-side riparian zones (Figure 4). These areas are frequently overgrazed while steeper slopes and land that is distant from water are grazed only slightly, if at all.

Short grazing periods alleviate the problem of grazing regrowth. When animals continuously occupy a particular pasture or range for an extended period during the growing season, they tend to re-graze plants they previously grazed. This is because all grazers prefer new succulent leaf tissue over

Research indicates that short-duration grazing gives higher returns per unit of land.

older, more fibrous leaves and stems. It is widely accepted that the resultant, repeated defoliation of certain plants leads to their physiological impairment and a decline in their vigor.

In the brief span (as little as 2-3 days) specified by S-DG periods, plants do not have time to re-grow much. Thus, the stress imposed by an immediate grazing of re-growth is avoided.

Having many pastures in a "grazing cell" (Figure 1a) provides long periods of rest during which plants can recover from grazing. As shown in Table 1, the rest period quickly increases in duration as the number of pastures or paddocks in a system grows, particularly as it approaches the range of 6-10 paddocks. This phenomenon, along with the control the manager can exercise over the length of the grazing period in a particular paddock, is critical. Ideally, when plants are young and growing, they should be allowed a relatively long period of rest from grazing, but not so long that they begin to go to seed and lose nutritive value.

Time control over grazing is in the manager's hands. Young growing plants need to maintain as much leaf area as possible for optimum growth and for recovery from being grazed. The arrangement of pastures and the relative ease with which animals can be rotated from pasture to pasture allows the manager to easily control the degree of grazing. Animals should be rotated quickly during periods of rapid plant growth and more slowly when the plants are naturally maturing or are dormant.

Wagon-wheel pasture arrangement facilitates animal handling and minimizes animal stress. Any system of grazing management that worked wonders for plants but compromised animal performance would be unacceptable. This has been a common complaint with such management approaches as rest-rotation grazing. With a radial design, however, animals are usually moved through the cell-center (which is familiar to them) when being shifted to the next pasture. Also, the next pasture is generally adjacent to where they were. Thus, they reportedly move easily, without force, and do not spend time exploring and fence-walking in the new pasture. The livestock are even reported to develop an eagerness and a sense of anticipation when a move is due. Such cattle respond well when the gates are opened, presumably because they want to get at the fresh forage in the new pasture.

Physical impacts of aggregated animals improve ecosystem functions such as nutrient cycling and water infiltration. These professed benefits are probably the most difficult for trained ecologists and scientists to accept on faith. Certainly they demand extensive research before being accepted as fact. Presumably the concentrated trampling of the ungrazed dead and dry vegetation facilitates decomposition of plant litter and promotes mineral cycling. Also, the breaking of soil crusts and of aggregations of algae and lichens are said to aid water infiltration and minimize capillary evaporation from the soil surface, a process similar to the way surface tillage does on fallow agricultural land.

WHAT DOES COMPLETED RESEARCH SAY?

As mentioned earlier, this concept of short-duration grazing is new to North America, and controlled research studies are few and young. From the standpoint of livestock production, however, early research results are supporting the hypotheses. For example, Texas researchers (Heitschmidt et al. 1982) found that, on an individual animal basis, cattle under S-DG gained weight at a rate equal to that of cattle on conventional year-long grazing. However, the two-fold higher stocking rate supported by short-duration grazing translated into a doubling of animal weight gains per acre of land, as compared to conventional grazing. Returns *per unit of land* represent the notorious "bottom line" to ranchers, particularly those that operate mainly on private land.

This same Texas research indicated that total forage plant production was as good or perhaps even higher under short-duration management than under conventional grazing. We stress, however, that these studies have been in place only for two years and do not represent a definitive answer on plant community response.

UTAH'S SITUATION

The major present limitation to increasing livestock production from Utah's ranges is a shortage of early spring forage. Even though forage may be abundantly available at other seasons, most ranchers cannot run more cattle than they can afford to feed with scarce and expensive hay during late winter and early spring.

Seeding ranges with crested wheatgrass (*Agropyron cristatum* and *A. desertorum*) was seen as a solution to this dilemma in the 1950s and 1960s. These wheatgrasses are highly productive and extremely tolerant of grazing, and they begin growth early in the spring (Figure 5). Now, however, many of these plantings are seriously

Increased weight gains and reduced animal stress are positive results of S-DG

declining in productivity, and the expense of reseeding is almost prohibitive. Therefore, ranchers must find ways to keep production high on the existing crested wheatgrass ranges.

Two common problems for managers of crested wheatgrass pastures are spot grazing and early maturation of the plant. Unless plants are grazed early in the growing season, they soon set seed and mature (Figure 6). Their nutritional value plummets, and animals prefer not to graze plants with large numbers of reproductive stems and seed-heads. The results include so-called "wolf plants" that use scarce soil moisture and nutrients but support virtually no grazing.

We hypothesize that, through short-duration grazing, we can greatly improve the efficiency of harvest of crested wheatgrass forage. If research confirms that hypothesis, these plantings can be used earlier in spring and further into early summer than at the present. Increases in stocking rates may also be possible.

UTAH-ORIENTED RESEARCH

To find out if S-DG should be recommended to Utah ranchers, we are using a grazing research station that is maintained by the Utah Agricultural Experiment Station in cooperation with the Bureau of Land Management. The area is located at the Tintic Range Research Station near Eureka in Juab County. Plans call for a 5-year research effort.

The grazing cell (Figure 1a and b) that has been established consists of 210 acres of crested wheatgrass range, seeded in the 1960s. The radial cell design contains 10 paddocks of about 21 acres each. Starting as early in April as current growing conditions permit, each paddock will be grazed for an average of three days by about 90 replacement heifers. A rotation cycle that uses all 10 paddocks will require about 30 days. We anticipate completing at least two cycles from April to early July. If the approach is as effective as we anticipate, we may be able to extend grazing even later into summer without suffering any reduction in cattle weight gains.

A broad range of topics will be researched during the experiment, with their major goal being an answer to *why* short-duration grazing works (or fails to work) on Utah rangelands. This kind of approach goes beyond merely demonstrating *if* a practice works or does not work. Such "mechanistic" or "basic" research is essential if we are to learn how grazing affects the survival and productivity of individual forage plants. That might be as important as learning whether the S-DG will "work" on Utah's rangelands.

Our research objectives will include specific studies on the following components:

Animal production. Daily weight gains of heifers managed under S-DG will be compared to those of similar animals grazing crested wheatgrass on the traditional season-long basis.

Animal behavior. We expect S-DG to have major effects on cattle behavior. How animals distribute themselves over the range available to them, how they utilize the cell center (watering area; see Figure 1b), and how they respond to the relatively dense animal population in small paddocks are crucial questions that will be monitored. In terms of our replacement heifers, the effects of such behaviors on breeding success will be particularly important.

Animal nutrition. Presumably, if short-duration grazing does maintain crested wheatgrass in a leafy, vegetative stage of growth for a longer period in spring, this should be reflected as a higher plane of nutrition for cattle under S-DG than for those under conventional grazing. Dietary quality and forage consumption rates will be measured to test this idea.

Forage use. Detailed records will be maintained on individual grass plants and on individual tillers (shoots) within a plant to see how frequently plants are grazed and regrazed and how subsequent re-growth is affected by being grazed. Over-all yield of the forage stand will also be measured.

Plant community change. A major consequence of improper grazing in arid Utah is a weakening of desirable forage plants, and their replacement by sagebrush. This is an insidious but measurable process. Permanent photoplots will be established so we can photograph the same plots of ground year-after-year to determine if the grass stand is weakening and sagebrush is invading.

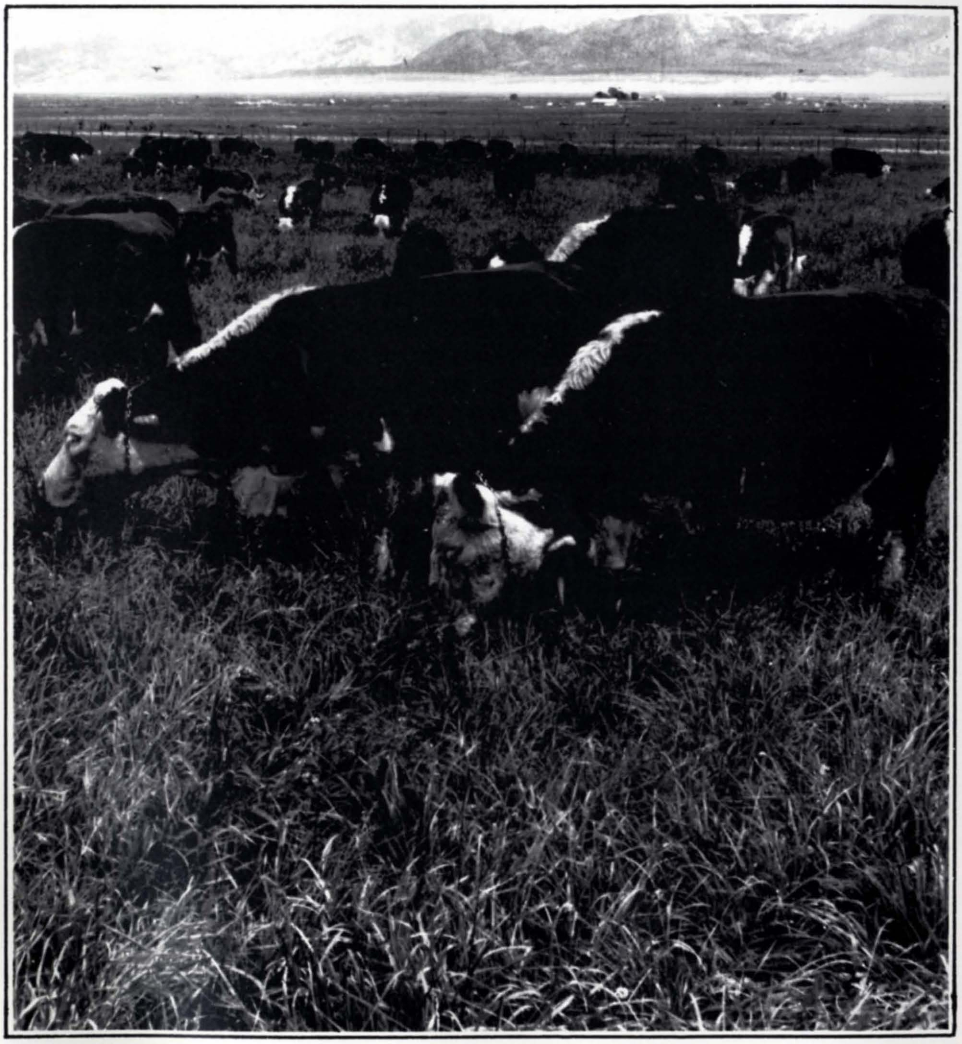
Watershed impacts. In any arid environment, the capture and use of precipitation by plants and soils are of paramount importance. Short-duration grazing has been heralded by some for its beneficial effects on water relations, while others have criticized it for its potentially negative impacts. Without question, hoof action by large numbers of animals in relatively small areas has a major impact. The question is whether or not the short duration of this impact and the relatively long recovery time available to the land (refer to Table 1) have special implications for watershed relations. Our long-term detailed analyses should help range managers decide : "Does short duration grazing improve plant-soil-water relations?"

TABLE 1. Effects that numbers of paddocks could exert on amount of grazing and rest a particular paddock might receive. Assume 200 acres, 100 cows, a 30-day rest between grazings and a 90-day grazing season (adapted from Savory 1978).

Number of paddocks	Size of paddocks (acres)	Stock density (animals/acre)	Avg. grazing period (days)	Number of grazings/ season	Total days of grazing/ season	Percent time rested/ season
6	33	3	6.0	2.50	15.0	83
10	20	5	3.3	2.70	8.9	90
14	14	7	2.3	2.79	6.4	93
18	11	9	1.8	2.83	5.1	94
22	9	11	1.4	2.86	4.0	95

The enhanced range condition increases stocking levels

Economics. As stressed earlier, dollars initially determine whether a particular practice will be adopted by livestock producers, and dollars finally decide if the practice will be continued. Through the use of computerized models, the economics of short-duration grazing will be tested for typical Utah ranches. These studies will be enhanced by on-site interviews with ranchers to define their management limitations, as related to S-DG. If short-duration grazing happens to be an unqualified success that greatly increased grazing capacity for a particular seasonal range, would the results also include a bottleneck somewhere else in the rancher's year-long management program? Obviously, the whole ranch system must be analyzed as the complicated, inter-meshed organization that it actually is.



CONCLUSION

If the promising findings of initial field trials in other states are borne out by detailed Utah research, short-duration grazing may be proclaimed the biggest change in and benefit to the ranching industry since the introduction of purebred cattle from Europe last century.

On the other hand, if certain aspects of S-DG are not universally applicable, or if certain management practices must be modified to fit Utah's local conditions, blind adoption of S-DG could write the final epitaph for economically ailing livestock enterprises. The answers can only come through such research as we described.

We ask interested ranchers and professional range managers to maintain close contact with the Utah Agricultural Experiment Station and the Range Science Department at USU as our research information on this new idea unfolds.

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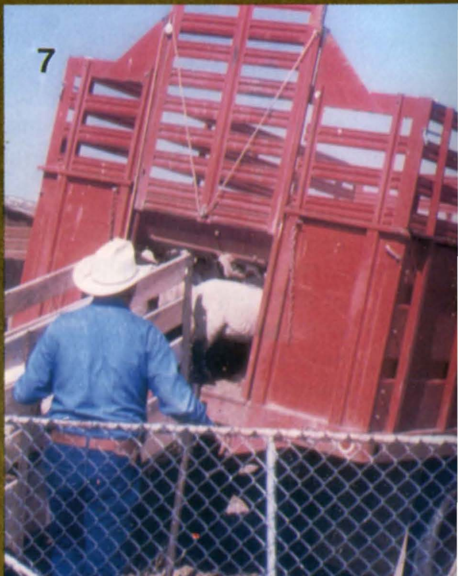
ABOUT THE AUTHORS

John Malechek is a professor of range science with research interests in grazing management, livestock nutrition and livestock behavior. He teaches and conducts research both in Utah and Brazil.

Don Dwyer, head of the Range Science Department, has extensive experience in range livestock production and grazing management. His research pursuits have taken him to Texas, Oklahoma, New Mexico, Utah, and recently, the Sudan in Africa.

CATTLE GRAZING WITH SHEEP



1. View of the study area depicting the major vegetation types and topography.

2. Open grassland vegetation that typifies many pastures. This grassland type has resulted from a long history of exclusive sheep use.

3. Hereford and Hereford X Angus cattle are representative of those used in the study.

4. Sheep grazing on average pasture in early summer.

5. Graph on page 41.

6. Visual evidence of how sheep favor snowberry. Shrubs at left center are ungrazed, while those in the center have received heavy use.

7. Sheep were transported to the range and lambs were taken to market by truck.

A Plus for Rangelands and Production

8. Cattle were hauled to handling corrals for sorting and assigning to pastures.

9. Animals were moved to sorting corrals for mid-summer and final weighings.

10. The efficiency of sheep production during the study is illustrated by this early morning view of the lambs being sent to market.

J. E. BOWNS and
D. H. MATTHEWS

PRODUCTION OF RED MEAT CAN OFTEN BE INCREASED on western ranges by achieving a proper balance of sheep, cattle, and game animals. So indicates research being conducted near Cedar City. Additionally, the desired red meat production can be associated with maintaining or improving range conditions.

The types of grazing animals are either more or less efficient as forage harvesters depending on various factors. Sheep and cattle, for example, differ in their liking for various forage plants and in their innate ability to use ranges. Cattle prefer grass. Sheep utilize grass but prefer forbs (broad-leaved herbaceous plants) and many shrubs.

Sheep are well adapted to many intermountain ranges because they make efficient use of shrubs, are able to negotiate steep, rugged terrain and can thrive on ranges with limited livestock water. Sheep production is, however, very labor intensive, and predation as well as other factors make sheep production unappealing to some operators. Cattle, on the other hand, require much less labor but are not well suited to steep, rough, poorly watered mountainous ranges.

Grazing one kind of animal for many years on a particular range can change its vegetation from one type to another. Prolonged sheep grazing often results in a range dominated by grasses. Conversely, prolonged cattle grazing may result in an increase of shrubs and forbs. Common use of a range by cattle, sheep, and wildlife often results in highly efficient use of that range, improved range conditions, and greater livestock production.

Gathering Data

A Utah State University study conducted near Cedar City is allowing us to evaluate the level of production and efficiencies of cattle and sheep grazed separately or together under continuous and deferred-rotation grazing and the vegetation responses to these treatments. This study is being conducted on 3,200 acres of leased land at an elevation of 8,500 feet, within a mosaic of aspen, oakbrush, low sagebrush, snowberry, and open grassland (Figure 1). The areas currently dominated by coarse grasses are a result of long periods of exclusive sheep grazing (Figure 2).

Cattle used in this study are of two genotypes: Hereford and Hereford-Angus crossbreds in a 2:1 ratio, ranging from 2 to 7 years of age (Figure 3). Calves are born during February and March. Ewes and lambs consist of straightbred Targhee and cross-bred Suffolk-Targhee and Finnsheep-Targhee genotypes (Figure 4). Ewes range in age from 1 to 7 years and are lambed in April each year. All animals are randomly assigned by genotype and age of dam to the various treatments and pasture groups each year.

Forage use is determined through standard range management procedures. Use of grasses and forbs is determined by measuring stubble heights and estimating utilization from height-weight relationships. Snowberry use is estimated by using stem diamete to leaf and stem weight relationships. Range condition trends are monitored with frequency and step-point sampling procedures every two years. Stocking rates are determined for each pasture by evaluating vegetation use and animal performance. Adjustments are made annually so that grazing pressure is nearly equal for each pasture.

Forage Preferences

After three years, we have data on forage preferences of cattle and sheep and the levels of their use of grasses, forbs, and snowberry (which is the most valuable feed-producing shrub on these ranges). Sheep use snowberry much more intensively than do cattle (Figure 5). Sheep grazed alone used this shrub to a level of approximately 32 percent (based on weight removed), while cattle used only 8 percent. Sheep and cattle grazed in common utilized snowberry at essentially the same intensity as did sheep grazing alone. Our data suggests that, by some range standards, the level of snowberry utilization is quite low. Sheep do not remove the entire stem, however, but merely strip the leaves, leaving the stems intact (Figure 6). The percentage of weight removed thus remains low. Unfortunately, this selective use of snowberry *leaves* results in the removal of nearly all of the plants' photosynthetic tissue. Eventually, this may have a more significant detrimental effect than the relatively low levels of use might indicate.

Utilization of forbs and grasses also varied with the grazing treatments. Sheep grazing alone made the greatest use of forbs and snowberry, but the least use of grasses. Cattle grazed alone made the lowest use of forbs and snowberry, but consumed large amounts of grass. Cattle and sheep grazed in combination made the highest recorded use of grasses and were intermediate in their use of forbs and snowberry. On the average, sheep and cattle when combined made the most efficient use of a pasture's forbs, grasses, and shrubs. Grazing sheep and cattle together also gave us the most efficient and even use of entire pastures by reducing the impact of selective use by each species of preferred plants and

Negative aspects of both sheep and cattle grazing are reduced with common use.

areas in each pasture. Common use exploited the beneficial aspects of sheep and cattle while reducing the negative aspects of each species.

Effects on Animals

To date, we have observed excellent production by both animal species and all treatment groups. Average daily gains have been slightly higher in continuous-grazed groups than in rotation groups, as measured by both progeny and dams of sheep and cattle (Table 1). Essentially no differences have been found in mean daily gains or weight changes between groups of animals grazed alone and those in mixed grazing groups.

Weight gains were higher for all animals during the spring to summer grazing period and were lower between summer and fall. This probably reflects the effects of maturity of the range forages in the late season and the seasonal rains that occur in late August and September. Ewes grazing alone had a higher maximum total average production of offspring in both years of the study: 52 and 57 pounds per 100 pounds of ewe, than they did when grazed in combination (Table 2). Sheep and cattle grazed together produced maximums of 42 and 39 pounds. Cattle grazing alone produced maximums of 27 and 28 pounds per 100 pounds of dam. These highly significant differences in offspring weight gains indicate the relative efficiencies of reproduction of the two species. The higher production by sheep than cattle was due in part to the multiple births among ewes versus single births for cows. Year differences were especially pronounced in the summer-to-fall grazing period, emphasizing variations in environmental conditions. Weight gains of offspring

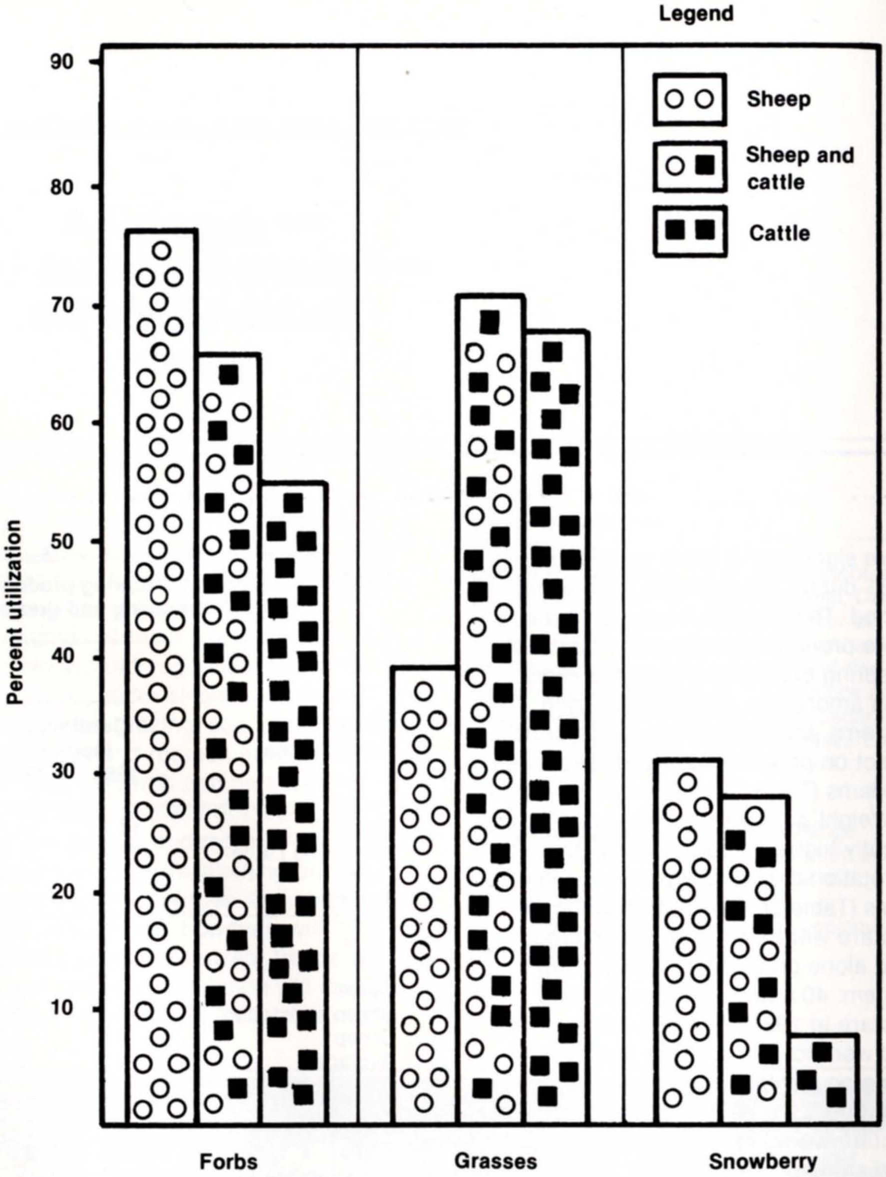


FIGURE 5. Utilization levels of forbs, grasses, and snowberry by sheep grazed alone, sheep grazed with cattle, and cattle grazed alone.

TABLE 1. Average daily gains by animal combination and grazing system (season), 1981-1982.

	Species grazed alone (pounds) 1981	1982	2-year avgs.	Species grazed together (pounds) 1981	1982	2-year avgs.
Calves, continuous	2.37	2.38	2.38	2.25	2.32	2.28
Calves, rotation	2.31	2.08	2.19	1.89	2.01	1.95
All calves	2.35	2.23	2.29	2.07	2.16	2.12
Lambs, continuous	.53	.54	.54	.46	.53	.50
Lambs, rotation	.49	.52	.50	.43	.47	.45
All lambs	.51	.53	.52	.44	.50	.47
Cows, continuous	1.61	1.59	1.60	1.44	1.67	1.56
Cows, rotation	1.44	1.30	1.37	1.18	1.24	1.21
All cows	1.53	1.45	1.49	1.31	1.45	1.38
Ewes, continuous	.15	.25	.20	.10	.18	.14
Ewes, rotation	.16	.24	.20	.11	.20	.16
All ewes	.15	.24	.20	.10	.19	.15

Rangelands grazed by sheep and cattle maintain a balance of forbs and grasses.

were significantly lower in 1982 than in 1981 during the sumer-to-fall grazing period. The season of grazing had a more pronounced effect on pounds of offspring produced among the ewes than among the cows. The grazing systems appeared to have little or no effect on pounds of offspring produced by dams (Table 2).

Weight gains per hectare were slightly higher in continuous-grazed than in rotation-grazed groups except for ewes (Table 3). Gains of offspring per hectare were highest in sheep groups held alone on a continuous grazing system: 40.3 and 40.7 pounds per hectare in 1981 and 1982, respectively, and were lowest in cattle groups held alone on a rotational grazing system: 27.8 and 23.4. Weight gains of dams per hectare were highest in cattle groups held alone on a rotational grazing system: 27.8 and 23.4. Weight gains of dams per hectare were highest in cattle groups grazed alone and were lowest in sheep groups grazed alone.

TABLE 2. Pounds of offspring produced per 100 pounds of dam body weight by period of grazing and grazing system[a] (1981-1982).

Animal Combination	Continuous (pounds) 1981	1982	2-year avgs.	Rotation (pounds) 1981	1982	2-year avgs.
Spring—summer period						
Cattle	14.7	14.7	14.7	15.2	15.2	15.2
Sheep and cattle	28.8	31.9	30.4	31.2	30.0	30.6
Sheep	49.7	50.4	50.0	46.7	46.0	46.4
Average	31.0	32.3	31.6	31.0	30.4	30.7
Summer—fall period						
Cattle	15.1	12.2	13.6	15.6	7.8	11.7
Sheep and cattle	13.3	9.1	11.2	9.6	6.7	8.2
Sheep	9.2	4.0	6.6	9.3	2.8	6.0
Average	12.5	8.4	10.4	11.5	5.7	8.6
Spring—fall period						
Cattle	29.8	26.9	28.4	30.9	23.0	27.0
Sheep and cattle	42.1	41.0	41.6	40.7	36.7	38.7
Sheep	58.9	54.4	56.6	56.0	48.8	52.4
Average	43.6	40.8	42.2	42.5	36.2	39.4

[a]Data adjusted for pasture size and days of grazing.

Numbers per Pasture

Another major objective of this study has been to determine optimum stocking levels for individual pastures. Livestock numbers and rotation dates were adjusted in each of 3 years to meet this objective.

Stocking levels rose by 25 percent in sheep-cattle continuous, 22 percent in sheep continuous and in sheep-cattle rotation, 18 percent in cattle continuous, 17 percent in sheep rotation, and 15 percent in cattle rotation pastures. Overall, a 20 percent increase has been implemented over a 3-year period. The average stocking level has increased from 3.68 acres allocated per animal unit month (one cow and calf or 5 ewes and lambs for one month) in 1980 to

TABLE 3. Weight gain per hectare in pounds by animal combination and grazing system (1981-1982).

	Continuous (pounds) 1981	1982	2-year avgs.	Rotation (pounds) 1981	1982	2-year avgs.
Cattle						
Progeny	28.2	27.1	27.6	27.8	23.4	25.6
Dams	19.2	18.1	18.6	17.2	14.7	16.0
Cattle and sheep						
Progeny	34.1	37.5	35.8	33.0	32.7	32.8
Dams	13.7	19.5	16.6	12.6	16.0	14.3
Sheep						
Progeny	40.3	40.7	40.5	37.6	35.0	36.3
Dams	7.0	13.2	10.1	7.3	14.0	10.6
Averages						
Progeny	34.2	35.1	34.6	32.8	30.4	31.6
Dams	13.3	16.9	15.1	12.4	14.9	13.6

Red meat production can be increased while range condition is maintained or improved.

2.96 acres/AUM in 1982. Although other factors were involved, a major reason for the increased stocking levels was the enhanced range condition that resulted from the changes in livestock distribution.

Preliminary trend data and observations indicate that these ranges are continuing to improve even at these relatively heavy stocking rates. At this point, the improvement appears to be most rapid in the pastures grazed by the combined animal species under the deferred rotation system. Time and further data analysis will support or refute these initial indications.

Summary

Results to date illustrate that red meat production can be increased while range condition is maintained or improved. Evaluations of both plant and animal responses are contributing to our knowledge of grazing systems suitable for similar western ranges. Currently, daily animal weight gains are slightly higher on continuously grazed pastures than on rotation pastures. If the rotation pastures improve in forage quantity/quality, however, this difference may decline or be reversed.

Animal production is currently higher during the first half of the rotation sequence. This may be due to weather conditions during late summer or to the levels of utilization prior to rotating pastures. Anticipated lighter utilization levels during the first half of the rotation may help alleviate this undesirable trend in animal performance.

Sheep have shown a higher annual production of red meat than cattle. Their efficiency is due in part to multiple births but may also indicate a more efficient use of the range forages.

The study area is toured regularly by individual stockmen, producer organizations, groups of U.S. and foreign students, scientists, and range managers. They all want to personally evaluate our evolving data on the production of red meat, animal compatibilities, and vegetation responses as they occur under single species and combination grazing, superimposed over continuous and rotation grazing. Results from this research can be applied immediately by many of these people to achieve greater and more efficient meat production while maintaining or improving the range resources. Only additional years of research, however, will determine whether current trends will persist and how vegetation will respond to these treatments over a longer time.

ABOUT THE AUTHORS

Darrell H. Matthews is a research associate professor in the Department of Animal, Dairy and Veterinary Sciences and professor of animal science and physiology at Southern Utah State College. He is in charge of the animal science research at the livestock and range branch experiment station in Cedar City. He has conducted extensive research in sheep breeding and management and in reproductive physiology.

James E. Bowns is professor of Range Ecology and shares a joint appointment in the Range Science Department at USU and Biology Department at SUSC. His professional emphasis is in range ecology and range management.

F. GOMM and W. HORTON

TESTING NEW GRASSES FOR RANGELANDS

AS RECENTLY AS 90 YEARS AGO, much of the western range was covered with waving stands of bunchgrasses. Left to profit-seeking cattle kings, sheep barons, and open-range policies, however, great expanses of that rangeland were soon so denuded that bands of sheep could be counted by their clouds of dust. Not until the early 1900s did farsighted ranchers and government agencies begin to realize that if grazing practices were not changed in a few years, most of the western rangeland would be of little value for grazing.

Of the 400 million acres of non-forested rangeland in the western states (40 million are in Utah), 82 percent are still considered to be in fair to poor condition.* In Utah alone, an estimated 15 million acres could benefit from seeding to adapted, superior, forage species. The result would be a four-to ten-fold increase over present production.

Past Perspectives

Reseeding research was started as early as 1895, when the federal government began grass plantings, but 1,500 trials were largely failures. Again in 1907, the Forest Service began seeding programs but 500 tests in 11 states gave only a 16 percent success rate, even on favorable sites. A. W. Sampson (The "Father of Range Management") pioneered in this early range improvement research at the Great Basin Experiment Station near Ephraim, Utah. Part of the early failures could be attributed to using grass species that were not adapted to harsh droughty conditions and to lack of proper management.

Experience, research, and public response have demonstrated that reseeding should not be applied to all rangeland. Many sites are too fragile because of slope, soil texture, or soil chemistry to permit heavy use or cultivation. Other sites have been classified as habitat for endangered plants and animals, and environment preservationists have been very vocal about not disturbing the natural beauty and association of native landscape. Nevertheless, artificial revegetation can fulfill a definite and important role in good range management on selected sites of much of the West's rangeland, but it should never be considered a cure-all for poor management.

Forage species such as smooth brome, timothy, orchardgrass, and alfalfa, introduced from the Mediterranean area by early immigrants to the U.S., were well adapted to the moist eastern states and to the irrigated valleys of the intermountain states. Economical reclamation of large acreages of abandoned, marginal farmlands and deteriorated, overgrazed, semiarid rangeland had to wait, however, until 1898. In that year, crested wheatgrass was introduced from Russia. Then, in 1915, it was proved adapted to the Northern Great Plains. Wherever crested wheatgrass has been able to thrive (almost anywhere sagebrush grows) the species has been a miracle grass. Today it grows on 12.5 million acres in North America.

Undoubtedly some sites that were plowed and planted to crested wheatgrass should not have been

*U.S. Dept. Agric., Forest Service. The nation's range resources. Forest Resources Report No. 19, Dec. 1972.

FIGURE 1. Interseeding of improved grasses and legumes into native meadows is gaining popularity but requires strict adherence to plant growth principles. Drilling into sod without first controlling native plant competition invites failure. Control by spraying native grasses with 8 oz/acre of *Roundup* three weeks prior to planting has given good results.

FIGURE 2. Talking with ranchers on the problem site results in more effective solutions and controls.

FIGURE 3. Working together, range scientists, state climatologists, soil scientists, and land managers are attempting to correlate weather information to forage production. This work will help ranchers plan toward a predicted amount of useable, grazable forage.

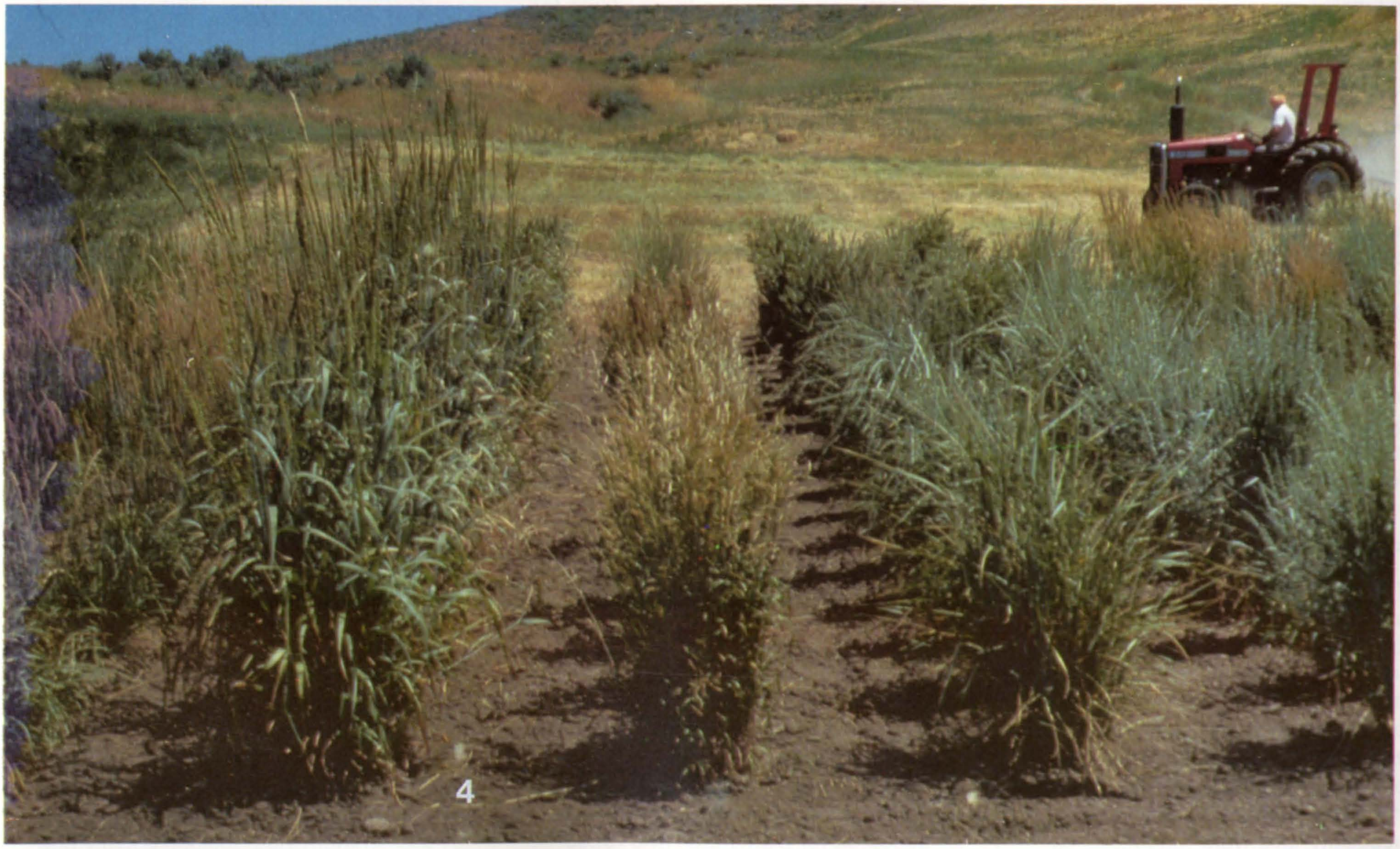


FIGURE 4. Test plantings of promising forage species must be made at many range sites as a way to determine the adaptability of new introductions and improved species from our breeding programs.

FIGURE 5. A new introduction, Russian wildrye (left), is far superior to the commercially available variety (right). Plant explorers and breeders seek new germplasm (seeds or plants) in Russia, China, South America, and even among our native, western species.

Research and testing will introduce new plants that are nutritious as forage and adaptable to the intermountain rangelands.

disturbed; others should have been planted to species other than crested wheatgrass. It is also undeniable that extensive monoculture plantings have encouraged increased populations of the black grass bug and other insects. Nevertheless, crested wheatgrass has given western ranges new life.

Much of the potentially productive range sites were planted during the 1950s and 1960s, but over 200 million acres still remain in poor to very poor condition. Because of low forage production and severe soil erosion problems, these sites must be brought under control and improved. High costs of seedbed preparation; lack of adapted introduced species; or high priced, low quality, and small supplies of seed of native species have restricted range revegetation programs.

Finding and Breeding Solutions

The purpose of the USU-based Forage and Range Plant Breeding Group of the USDA's Agricultural Research Service is to introduce, select, or create new plant materials that are easily established; persistent; high producing, palatable, and nutritious as forage; and are adapted to the harsh environments of the intermountain rangelands. Of necessity, this work requires cooperation with foreign countries, from which our scientists collect new germplasm (plants or seeds having genetic characteristics different from our local strains). Cooperation is also necessary with personnel of: Utah State University, other state universities, Forest Service, Bureau of Land Management, Soil Conservation Service, other federal agencies, Utah Department of Natural Resources, and private companies; as well as with individual ranchers.

Breeding of forage grass by Agricultural Research Service scientists at Utah State University has been underway since the 1950s, but it wasn't until 1974 - 1978 that increased emphasis was placed on improvement of selected hybrids, improved strains within species, introducing new germplasm, and evaluating these plants for rangeland use.

The diverse character of intermountain rangelands requires a large number of study sites. During the last 4 years, we have established 90 plantings at 30 sites in Wyoming, Idaho, and Utah. Over the same period, seed has been provided to many cooperators in nearly all of the western states.

At most sites, plants have been established by transplanting and by drilling seeding. In the transplant studies, we cultivate between the rows and between plants within rows to give each plant the most optimum soil and growing conditions available under the prevailing climatic and site conditions. If the plant fails under such favorable conditions, it certainly would not survive if planted as seed. In the subsequent drilled studies, the seeds are planted in rows one foot apart with approximately 25 live seeds per foot of row. To be successful the drilled seeds must germinate, establish, and survive against natural plant competition.

The performances of new plant materials are compared to those of standard varieties and species generally accepted for planting on arid rangelands. To fully determine their potentials for use on rangeland, forages must be grazed. In our studies we determine their establishment characteristics, phenological development, longevity, herbage yields, palatability, nutritive quality, root weights, and root reserves. In many respects, some hybrids are proving superior to parental species and commercially available varieties. The following list of hybrids and experimental selections are under special consideration:

Improved standard type crested wheatgrass (*A. desertorum*)

Hybrid of fairway and standard wheatgrasses (*A. desertorum* × *A. cristatum*)

Hybrid of quackgrass and bluebunch wheatgrass (*A. repens* × *A. spicatum*)

Hybrid of quackgrass and standard crested (*A. repens* × *A. desertorum*)

Hybrid of quackgrass and fairway crested (*A. repens* × *A. cristatum*)

Hybrid of bluebunch and thickspike wheatgrass (*A. spicatum* × *A. dasystachyum*)

Hybrid of intermediate wheatgrass (*A. intermedium* × *A. acutum*)

Hybrid of basin wildrye and Altai wildrye (*Elymus cinereus* × *E. angustus*)

Improved Russian wildrye (*E. junceus*)

Included in our testing, also, are recent or soon to be released cultivars from the Soil Conservation Service Plant Material Centers:

Magnar basin wildrye (*Elymus cinereus*)

Rosana western wheatgrass (*Agropyron smithii*)

Barton western wheatgrass (*A. smithii*)

Critana thickspike wheatgrass (*A. dasystachyum*)

Ephraim creeping crested wheatgrass (*A. cristatum*)

Paiute dryland orchardgrass (*Dactylis glomerata*)

Bandera penstemon (*Penstemon strictus*)

Appar Lewis flax (*Linum lewisii*)

P739 bluebunch wheatgrass (*A. spicatum*)

Prostrate kochia (summer cyprus) (*Kochia prostrata*)

Palmer penstemon (*Penstemon palmeri*)

Lutana milkvetch (*Astragalus cicer*)

Nezpar Indian ricegrass (*Oryzopsis hymenoides*)

Delar small burnett (*Sanguisorba minor*)

Quackgrass × Bluebunch Wheatgrass (RS) Hybrids

Considerable variability still exists in the populations used in the studies of this

The ultimate test for forage plants is how they respond to heavy grazing.

crossbreeding; however, continued selection for desirable characteristics has improved the forage quality of the RS hybrids. RS-1 and RS-2, registered germplasm, are more uniform and express the characteristics for which their parental clones were selected. RS-1 was selected from bunch type plants while RS-2 was selected from plants that expressed limited annual rhizome growth.

Although not as drought tolerant as we had hoped, the resultant RS hybrid appears best adapted to areas with 15 inches or more annual precipitation. Exceptional stands are established near Scipio and Howell, Utah. In spaced plantings, it is a large, robust, leafy plant with leaves carried well up the seed stalk. In drilled plantings, it is a medium-sized plant with fine stems. It maintains its green color later into the growing season than either crested or intermediate wheatgrasses and appears to be relatively more palatable late in the season.

In pasture mixtures, the RS hybrids developed more slowly than orchardgrass and smoothbrome, and first-year stands of the hybrid were not as vigorous. Clipping studies, however, showed that the hybrid plants recovered rapidly after frequent, close clippings and yielded considerably more herbage than their parental species (Table 1). Generally, root weights and root soluble-carbohydrates were higher from clipped hybrid plants than the parent species.

Of particular interest, our studies and cooperative plantings indicate that the RS hybrids have a surprisingly high salt tolerance under wet meadow conditions and are thriving as well as tall fescue.

Field herbage yields of the RS hybrid generally have been intermediate to those of other species (Table 2). Late in the season, however, the protein concentration has remained relatively high compared to crested wheatgrass.

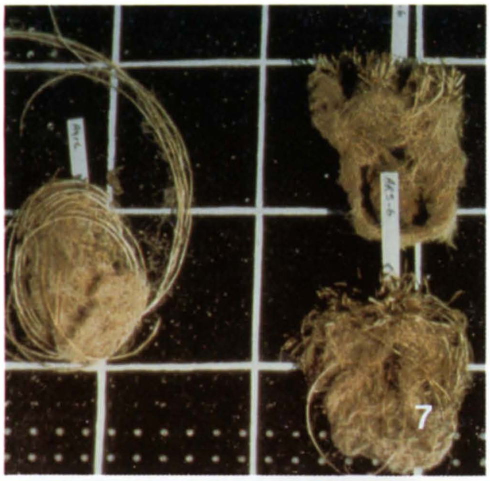
TABLE 1. Total accumulated yields of herbage from grasses harvested at different intervals between clippings.

	Accumulated clipping yields in grams per pot						
Week intervals[1] between clippings	Agre[2]	Agcr	Agde	Agsp	Agre × Agcr	Agre × Agde	Agre × Agsp
1 (clipped weekly	6.7	6.8	6.1	5.0	8.5	7.7	12.8
2 (clipped biweekly)	6.6	6.9	6.4	5.6	9.0	8.0	13.0
3	6.6	7.1	6.3	5.7	8.7	7.8	14.2
4	7.6	7.2	6.4	5.9	9.4	8.0	13.9
6	7.7	6.8	6.4	5.7	9.3	7.7	13.6
8	7.8	6.8	6.5	5.4	9.5	8.4	13.9
10	8.0	6.5	6.6	5.9	9.4	8.3	14.1
Control	7.3	6.6	5.6	6.5	9.4	9.9	13.1

[1]All plants, except the control, were first-clipped at the same date. The control and all other treatments were last-clipped 10 weeks after the first-clipped date.
[2]Agre = quackgrass; Agcr = Fairway crested wheatgrass; Agde = Standard crested wheatgrass; Agsp = bluebunch wheatgrass.

TABLE 2. Yield of selected species and varieties of grasses at several range sites, 1982.

	Herbage yield in pounds per acre					
	Woodruff	Tintic	Morgan	Stone	Cokeville	Fillmore
Fairway crested wheatgrass	1970	2230	1395	635	—	900
Nordan crested wheatgrass	2920	1905	2030	740	2680	1680
Greenar intermediate whgr.	3140	2050	2650	365	2025	2270
Oahe intermediate whgr.	2370	2380	2830	550	2400	2200
Luna pubescent wheatgrass	—	2400	720	—	1770	1960
Jose tall wheatgrass	1965	2715	2200	—	1155	—
Alkar tall wheatgrass	1960	1600	—	—	470	1710
RS-1 hyb. wheatgrass	1625	2325	960	160	750	1530
RS-2 hyb. wheatgrass	1630	2340	1225	—	675	1680
Vinall Russian wildrye	1015	1350	650	—	1065	103
Bozoisky Russian wildrye	1390	1655	530	135	1120	—
Magnar basin wildrye	625	—	700	—	1160	960
Lincoln smoothbrome	1890	—	565	—	1680	1240
Manchar smoothbrome	1750	—	1305	—	1140	1920
Regar meadowbrome	1180	—	1480	—	—	1860
Latar orchardgrass	—	—	260	—	—	—
Critana thickspike wheatgrass	1200	—	375	—	1510	—
Alta tall fescue	640	—	535	—	—	—
Bluebunch × thick-spike wheatgrass	1190	—	385	—	375	—
Rosana west. wheatgrass	1095	—	1940	—	655	1680
Sodar stmbnk wheatgrass	925	970	660	—	390	—
P-27 siberian wheatgrass	—	—	—	385	—	2610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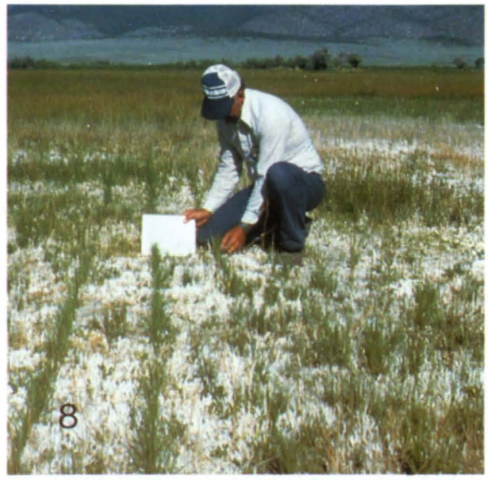
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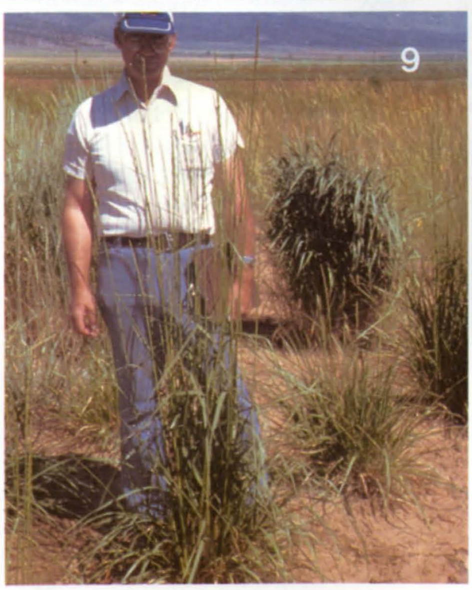
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FIGURE 6. The hybrid (quackgrass × bluebunch wheatgrass) brings together the desirable qualities of both parents. Negative traits, as weediness in quackgrass, are bred out. This new species of grass is now being tested under many site conditions to determine where it is best adapted and how it might best be used.

FIGURE 7. Roots of grasses grown in six-inch pots were matted into "birdnest" clumps. Degrees of rhizome production can be seen in quackgrass. (*A. repens*), left; bluebunch wheatgrass (*A. spicatum*), right; and their hybrid cross, center. Center-top is root of the RS-1 selection (bunch type) and center-bottom is the RS-2 selection with moderately weak rhizomes.

FIGURE 8. Direct seeding of the salt-tolerant hybrid (quackgrass × bluebunch wheatgrass) into a saline meadow produced a successful seedling establishment.

FIGURE 9. The hybrid of Altai wildrye by Great Basin wildrye is a tall coarse-leafed plant adapted to overflow lands, saline sites, and special-use areas where windbreak or snow catchment is desired.

FIGURE 10. The F_1 generation hybrid (quackgrass × crested wheatgrass) is a sterile plant with a moderate creeping habit and good leaf production making it ideal for transplanting to special-use areas and waterways.

Russian Wildrye

Improved selections from the strain, Bozoisky, recently introduced from Russia, appear far superior to Vinall, a widely used cultivar of Russian wildrye. In spaced plantings, the improved selection is a taller, more robust plant than Vinall. It also appears to have good seedling vigor—similar to Swift, Mayak, and Cabree. Its rate of root extension and plant height generally exceed those of other selections, and forage production is superior.

Although Russian wildrye sets seed earlier than most of our range species, its leaf development is indeterminate and the basal leaf growth remains green late into the season. Once established, Russian wildrye is an exceptionally determined competitor and will stop invasion of annual weeds. Selections from the Bozoisky strain of this exceptionally drought and salt tolerant species soon should be released for commercial seed production.

Crested Wheatgrass Hybrids

Quackgrass × crested wheatgrass hybrids have not been as exciting as some of the other crosses and are not likely to replace standard crested wheatgrass, except possibly in specialized situations. The F_1 generation of the hybrid (*A. repens* × *A. cristatum*), which is sterile, is showing considerable promise in the Northern Great Plains on specialty sites where it can be started from vegetative sprigs. The sterile F_1 is a weak creeper, forming a loose sod. Individual plants are very uniform in growth characteristics and they carry an abundance of leaves high on the seed stalks. Although seed stalks are formed, no viable seed is produced. This plant could be used to advantage on waterways, mine spoils, and other areas of high intensity value where "sprigging" can be done economically.

The standard crested by fairway crested wheatgrass hybrid is showing excellent establishment qualities under very harsh site conditions. Plantings made at the USAF Eagle Range, west of Great Salt Lake, show it to be promising for planting on these and other low rainfall, salt desert shrub sites. At other sites the hybrid may produce more forage than either parent.

Wildrye Hybrid

The Great Basin wildrye by Altai wildrye hybrid is a huge plant with heavy, coarse stems. Although this plant may not prove to be as palatable as others, it could be considered for plantings designed to catch and hold snow, or for special lambing or calving grounds. It apparently is not tolerant to close grazing.

New Releases from SCS

The soon-to-be-released selection of crested wheatgrass, Ephraim, is rhizomatous and might find favor on sites where soil movement could be a problem. Paiute is a drought tolerant strain of orchardgrass introduced from Turkey. Some reports suggest that when established it is as drought tolerant as crested wheatgrass. Time will tell. Bandera penstemon and Appar Lewis flax are forbs selected from native species that appear especially useful in mixed plantings for the sagebrush zone. P739 is a selection from native bluebunch wheatgrass. Prostrate summer cypress (Kochia) is a perennial halfshrub, introduced from Russia. It is drought tolerant, reseeds itself, and produces a considerable amount of forage palatable to livestock. Good stands are easily established from transplants, but great care must be taken to collect and store viable seed. It is expected that this Kochia will be more widely used in mixed range plantings.

Proper evaluation of these and other new and exciting grasses requires continued work of testing new materials as they become available. Growth characteristics must be noted and evaluated for potential use in land management, forage production, or conservation.

The ultimate test for forage plants are: how well do they withstand grazing pressure, are they acceptable to animals, and do they reliably produce a large quantity of nutritious herbage? Because the ARS testing program is not designed to evaluate animal responses, pasture experiments must be completed by personnel of Soil Conservation Service Plant Materials Centers or by Agricultural Experiment Stations.

ABOUT THE AUTHORS

F. Bryant Gomm is a USDA range scientist working with the Agricultural Research Service. He holds the BS degree in Vocational Agriculture and MS and Ph.D. degrees in Range Science. All degrees are from Utah State University. He has specialized in rangeland, meadow, and pasture improvement at Bozeman, Montana; Flagstaff, Arizona; and Burns, Oregon. Presently, he is with the ARS Forage Breeding Team at USU, Logan, Utah.

W. Howard Horton is a native Utahn. After 15 years in the livestock business in southern Utah, he has returned to Utah State University to complete a BS degree in Range Science. He is employed as a range scientist with the Agriculture Research Service, USDA, located at Logan, Utah.

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G. F. GIFFORD,
W. HUMPHRIES, and
R. A. JAYNES

Introduction

In the Rocky Mountain region, mature aspen forests are replaced over time by evergreen conifers unless some form of catastrophic disturbance (i.e., fire, disease, clearcutting) occurs. When such a disturbance does destroy the overstory canopy of an aspen forest, the aspen quickly sprout from their roots and grow faster than the other vegetation. Aspen stands thus tend to perpetuate themselves.

Now that people are limiting natural fires and clearcutting, however, many areas once dominated by aspen have become coniferous forests. Available literature and preliminary modeling efforts strongly suggest that the aspen-to-conifer succession significantly reduces water yields (Jaynes 1978). Besides decreasing natural water yields, the expansion of conifer acreage may also be significantly reducing the potential gains in water yields that are expected through snow augmentation by cloud seeding.

Runoff volumes from forest areas depend on the seasonal consumptive-use patterns of the prevailing vegetation type and the influence of the respective canopies on incoming precipitation. Reductions in runoff volumes, and hence in the water available to downstream users, that follow aspen-to-conifer conversions can, therefore, be related to transpiration and canopy interception studies.

FIGURE 1. View of spruce-fir canopy from within the stand. Canopy coverage is about 70 percent.

FIGURE 2. View of aspen canopy from within the stand. Canopy coverage is about 82 percent.

ALL TREES ARE NOT EQUAL

Our primary objective was to achieve a preliminary quantification of any reduction in runoff associated with shifts from aspen to conifers.

Aspen Forests in the Western U.S.

Quaking aspen (*Populus tremuloides* Michx.) is the most widely distributed tree in North America. For example, this species occupies approximately 1.3 million hectares (3.3 million acres) in the Colorado River drainage area, almost all of it in the Upper Basin. About 75 percent of those acres are National Forest land. Aspen is recognized for its multiple values; yet, in the West, it has received relatively little management or research attention (Mueggler 1976). About 1,106,000 hectares (2,765,000 acres) of aspen are classified as being harvestable on a commercial basis.

Aspen is usually found between 2,188 m (7,000 ft) and 3,438 m (11,000 ft) elevations, in pure stands or interspersed among conifers in the subalpine, mixed conifer, and cooler portions of the ponderosa pine type. Aspen is so closely associated with these conifer types, especially Douglas fir and Engelmann spruce, that it sometimes is included with them for inventory and management purposes, particularly in the lower Colorado Basin, where aspen accounts for only about 46,000 hectares (115,000 acres) of the commercial forest land (Hibbert 1979). Farther north, in central Colorado and eastern Utah, aspen is much more extensive, often occurring in pure stands of up to several thousands of hectares.

Aspen has generally been regarded as a fire-induced successional species that can dominate a site primarily by root sprouting. Without fire or other disturbance, aspen may be replaced by conifers in a single generation. In other areas, conifer invasion may take much longer (Mueggler 1976). Harvesting and controlled burning are considered viable ways to keep aspen from being displaced by conifers.

The climate where aspen grows is essentially the same as that found in forested areas of the closely associated lower subalpine and mixed conifer types. Mean annual precipitation ranges from about 50 to more than 100 centimeters (20 to 40 inches), half or more falling as snow.

Literature describing the impact of successional trends on water yields within the aspen-conifer complex is not yet available. What we have, pertains only to management implications within existing aspen forests. If forested watersheds are to be optimally managed for water (and other) yields, data-based, reliable computer models are needed. Our research was a step in that direction.

Monitoring Transpiration in Aspen and Associated Conifers

Initial studies using heat pulse velocity (HPV) techniques* to measure transpiration (water lost by trees) were conducted on three tree species in the Utah State University forest in the Wasatch Mountains between July 15 and November 1, 1979. The forest is situated about 15 km south of the Utah-Idaho border at an elevation of about 2600 m (8300 ft). Aspen (*Populus tremulodies*), subalpine fir (*Abies lasiocarpa*), and Engelmann spruce (*Picea engelmannii*) stands are interspersed with open meadows.

The study* involved 26 aspen, 20 Engelmann spruce, and 20 subalpine fir. All measurements were made under conditions of readily available water, no root resistance and high potential evapotranspiration. On the day before sampling was to begin, each tree was supported by ropes, and a reservoir that had been created around the base of each tree was filled with water. Each tree then was severed under water at its base. By permanently sealing the reservoir, we insured that all water consumption from the reservoir would be due to uptake by the tree. Each tree stem was fitted with thermocouples** and heat probes at various depths for HPV measurements of its sap velocity profile. This profile, multipled by the water-conducting cross-sectional area of the stem, was used to estimate volumetric water flow through the trees. After all trees for each species were sampled, regressions were developed for each species to correlate indicated transpiration (as measured by water uptake from the reservoir) with computed transpiration based on HPV measurements (as determined by Swanson's model (1962)) and appropriate cross-sectional areas.

Sample trees were selected to provide:

1. A full range of tree sizes.
2. For each species, a full range of site characteristics such as slope and aspect.
3. Road access, so water could be pumped to them from a truck.

*Descriptions of which will be found in "A Preliminary Quantification of the Impacts of Aspen to Conifer Succession on Water Yield Within the Colorado River Basin (A Process Aggravating the Salt Pollution Problem)." Gifford et al. Hydraulics & Hydrology Series. UWRL/H-83/01. USU.

**Thermocouples (used in pairs) allow an investigator to measure the rate of heat transport in a tree stem, a rate that is related to how fast the sap is moving. That velocity, multiplied by the water-conducting cross-sectional area of the stem, can be correlated with measured transpiration (use of water) values. Completed research (Ibid., Gifford et al.) suggests that transpiration can be predicted by correlation with volumetric flow rates (determined from a series of HPV measurements) and information on the conducting area of the tree at the time of sampling. If such a correlation gives good results when developed using values from various trees under various conditions, it could be widely applied to intact trees.

Studies using heat pulse velocity measured transpiration levels of Aspen, Engelmann spruce and fir.

Sampling only trees near roads did introduce an edge-effect bias. Proximity to roads was essential, however, to allow us to supply measured quantities of water to each sampled tree.

Validity of Results

When averaged over large numbers of data points, we found that actual transpiration losses from a tree correlated well with the losses indicated from HPV calculations. All species responded that same way.

By sampling a large number of trees over an entire summer, we attained the quality and quantity of correlations that we needed for predictive purposes. The best correlation between actual and computed transpiration for each species was characterized by a high coefficient of correlation that was statistically significant at the 99 percent level. By combining our regressions and measurements, we could confidently estimate transpiration by live trees of the three species studied.

The methods and regressions developed in our 1979 study appear suitable for indexing transpiration losses for live aspen, Engelmann spruce, and subalpine fir in northern Utah. When collected simultaneously with other hydrologic and meteorologic data, such information can be used to develop quantitative water balances for the species studied. The final result can be an evaluation of which tree type is most likely to optimize the flow in associated streams.

Field Measurements of Transpiration

After working with the severed trees in their sealed reservoirs, we instrumented (with thermocouples and heat probes) an aspen stand and a nearby spruce-fir stand. The aspen stand has approximately 1,090 trees per hectare (436 trees/acre) with a dbh (diameter-breast-height) range from 8.6 to 43.2 centimeters (3 to 17 inches). The spruce-fir stand has approximately 2,125 trees per hectare (850 trees/acre) with a dbh range from 5.0 to 40.4 centimeters (2 to 16 inches). Both stands are located on gentle slopes of perhaps 2 to 4 percent. Canopy coverage averaged 80 percent for the aspen stand and 74 percent for the spruce-fir stand (Figures 1 and 2).

Within each stand we selected 12 trees, four of each species that had dbh values of approximately 10.2 cm (4 inches), for monitoring sap velocities. Each tree was instrumented with three sets of thermocouples and heater probes. Three trees of each species were monitored from near dawn to dusk at approximately 90-minute intervals on selected days from June 30, 1980, to June 30, 1981. Indicated transpiration values derived for each species on each sampling date are shown in Table 1. The indicated water losses are approximations, and the values were utilized in adjusting the plant activity index utilized as part of the ASPCON model described later. Typical average heat pulse velocities (sap velocities) are shown for four dates in Figure 3 and computer flow rates are given in Figure 4. Indicated water loss data (given in Table 1) were calculated through application of appropriate regression formulae (Ibid., Gifford et al.).

ASPCON Model Calibration and Modification

Jaynes (1978) developed a model (ASPCON) that describes the hydrology of aspen-to-conifer succession. The ASPCON model consists of a series of moisture storage compartments connected by transfer equations that systematically deal with each set of input data. As moisture enters and interacts with a watershed, a certain amount is lost to the atmosphere via evapotranspiration; the remainder may become streamflow or percolate deep into the soil.

ASPCON treats a watershed as a single-series, moisture storage "tank." Model coefficients related to watershed characteristics represent averaged values. The model calculates weekly water budgets throughout one water-year (October 1 to September 30). System input includes only precipitation and average weekly air temperatures. For our use, the model was calibrated on the West Branch Chicken Creek Watershed (CCW), Davis County Experimental Watershed in Utah (Jaynes 1978).

We modified ASPCON to reflect our recently obtained information about seasonal plant activity patterns and relative consumptive use rates. In particular, ASPCON was adjusted so it would predict streamflows for watersheds that might contain spruce, aspen or fir. Our slightly modified version of ASPCON was named SAFMOD.

Modeling Results

SAFMOD had the same structure as the ASPCON model. Since it was desired to compare the watershed hydrology of spruce, aspen, and fir forests, the coefficients for the grass-forb community in ASPCON were changed to reflect spruce forest conditions. The conifer community coefficients in ASPCON for Plant Activity Index (PAI) and relative comsumptive use (crop coefficient) were altered to reflect our new data for spruce and fir. The PAI and crop coefficient were similarly adjusted for aspen. The rooting depth coefficient for all three types was set at 1.0 to allow a better assessment of transpiration differences resulting from the changes mentioned above. All coefficients that were manipulated during the initial calibration of ASPCON and are independent of watershed cover were not altered.

SAFMOD was initially applied to determine the sensitivity of the model to the aspen crop coefficient. The results suggested that any possible errors made in estimating the aspen crop coefficient would not have a major effect on runoffs modeled by SAFMOD. The precipitation and active moisture input patterns in SAFMOD resemble those in ASPCON.

The snowpack melts slightly earlier and transpiration begins much later under aspen forest conditions than when conifers dominate the watershed. The result is that significantly greater amounts of runoff occur under aspen forest conditions. The SAFMOD hydrographs for the three forest types are similar for the portions of the year not shown in Figure 5.

The SAFMOD predicted annual water budgets for a year in which 119.4 cm (47 in.) of precipitation were received, are given in Table 2 for different combinations of forest communities. First, succession from aspen to spruce was examined. Second, aspen to fir succession was studied. Finally, aspen to both spruce and fir succession was tested.

The value for streamflow plus soil moisture change is presented, since net change from the initial soil moisture at the end of the year will affect the following year's runoff (the soil moisture must be recharged prior to runoff).

The SAFMOD calculated amounts of streamflow reduction that are likely to occur as aspen is replaced by either spruce or fir are shown in Figure 6. Spruce forests are predicted to reduce streamflow by 15.0 cm (5.9 in.) over aspen-dominated conditions. Fir forests are expected to reduce streamflow by 11.4 (4.5 in.). When streamflows plus changes in soil moisture were examined, spruce produced a difference of 18.5 cm (7.4 in.), and fir a difference of 7.1 cm (2.8 in.).

Summary and Conclusions

The limitations inherent in this preliminary study include:

1. The predicted hydrology of the aspen-conifer environment is only as good as the algorithmic logic of the modified ASPCON model. The same logic may not be applicable to all parts of the aspen type within particular areas.

2. Extrapolation of modeling results on the Chicken Creek Watershed near Farmington, Utah, may not be justified in every instance.

TABLE 1. Indicated water loss from aspen, Engelmann spruce, and subalpine fir on various sampling dates. Indicated water losses are approximations and are relatively utilized to adjust the plant activity index of the ASPCON model.

Date	Indicated water loss (cm^3)[1]		
	Aspen	Engelmann Spruce	Subalpine Fir
6-30-80	3,859	3,631	3,185
7-02-80	2,392	4,864	1,942
7-09-80	8,389	11,643	4,957
7-10-80	10,091	9,673	5,179
7-16-80	9,583	9,320	4,620
7-17-80	7,231	10,317	4,318
7-18-80	9,609	10,375	4,338
7-21-80	9,673	10,539	4,494
7-22-80	11,322	12,626	4,820
7-23-80	10,909	10,476	4,733
7-30-80	5,944	6,283	3,105
7-31-80	6,570	5,168	3,216
8-01-80	6,234	5,417	3,194
8-05-80	7,214	7,138	3,249
8-06-80	8,101	10,796	3,192
8-07-80	6,513	8,368	3,461
8-11-80	5,573	7,094	2,614
8-20-80	3,176	4,337	1,349
8-21-80	4,449	5,777	2,222
8-26-80	2,977	4,925	1,628
8-27-80	2,739	5,455	2,435
8-28-80	3,253	4,756	2,282
9-01-80	2,074	3,517	1,834
9-02-80	2,377	4,446	2,010
9-03-80	2,198	4,506	1,992
9-10-80	967	1,025	608
9-12-80	619	590	197
9-16-80	2,356	3,550	1,556
9-17-80	2,890	5,028	2,236
9-18-80	2,477	4,764	1,904
10-04-80	—0—	2,992	1,499
10-11-80	—0—	1,859	1,405
10-18-80	—0—	—0—	—0—
11-01-80	—0—	220	38
11-08-80	—0—	79	15
11-15-80	—0—	156	62
4-25-81	—0—	1,772	433
4-28-81	—0—	1,534	576
5-01-81	—0—	4,206	1,342
5-05-81	—0—	2,707	506
5-09-81	—0—	189	87
5-12-81	—0—	2	75
5-19-81	—0—	3,636	1,101
5-23-81	—0—	635	126
5-30-81	—0—	5,640	1,747
6-02-81	—0—	2,060	635
6-09-81	13	4,786	1,306
6-10-81	—0—	8,028	2,489
6-11-81	—0—	9,332	2,037
6-17-81	—0—	7,818	1,463
6-18-81	—0—	9,313	1,764
6-19-81	—0—	7,928	1,644
6-22-81	1,184	9,414	1,704
6-23-81	1,425	8,724	1,716
6-24-81	2,264	12,379	1,747
6-29-81	3,066	7,998	1,660
6-30-81	2,565	5,825	1,074

[1]Each value represents the average of three trees.

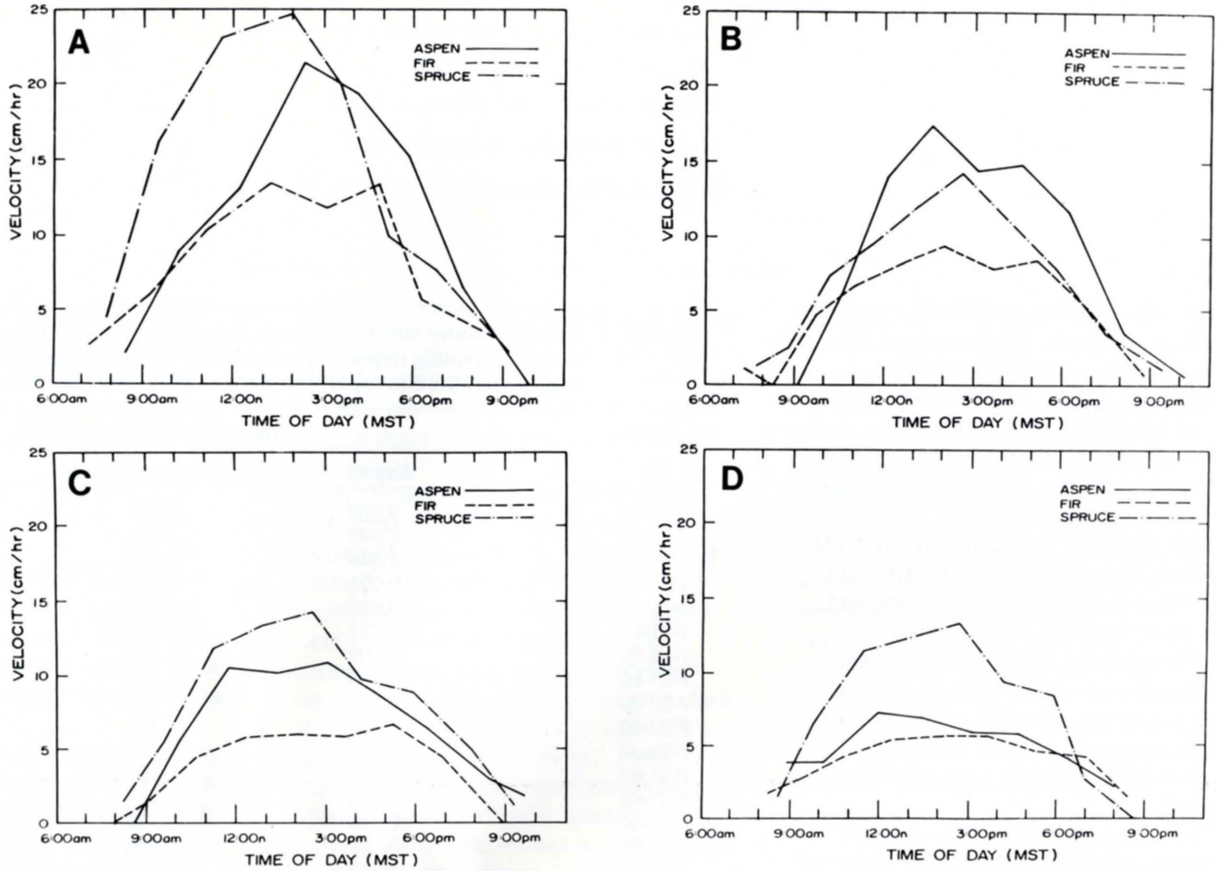

FIGURE 3. Average sap velocities of the three tree species on four select dates : A is July 9, 1980, B is July 30, 1980, C is August 21, 1980, and D is September 17, 1980.

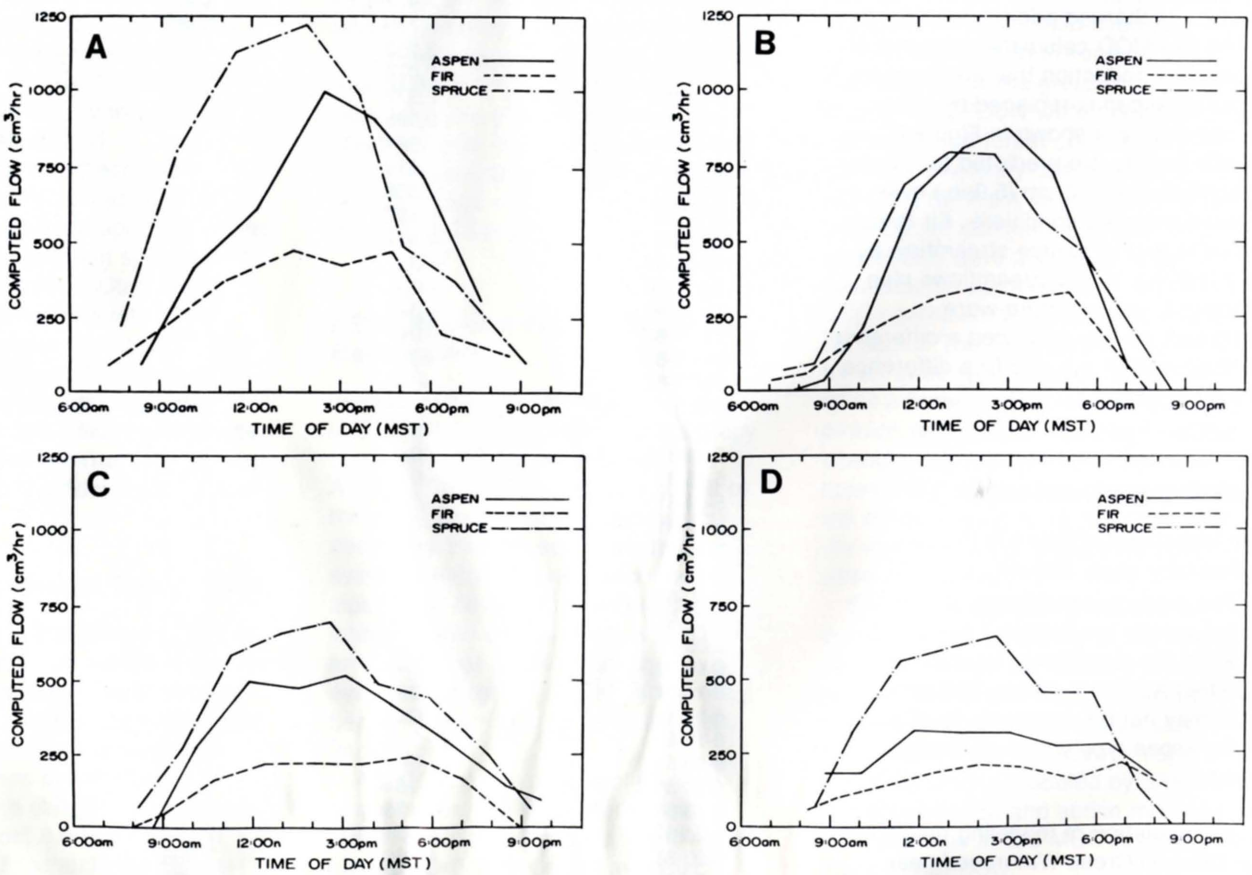

FIGURE 4. Average computed flow rates of the three tree species on four select dates: A is July 9, 1980, B is July 30, 1980, C is August 21, 1980, and D is September 17, 1980.

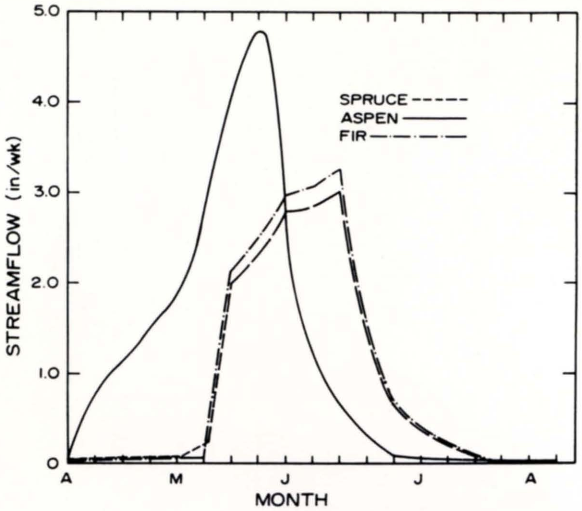

FIGURE 5. Spring runoff hydrographs for the Chicken Creek watershed when dominated by spruce, aspen and fir forests.

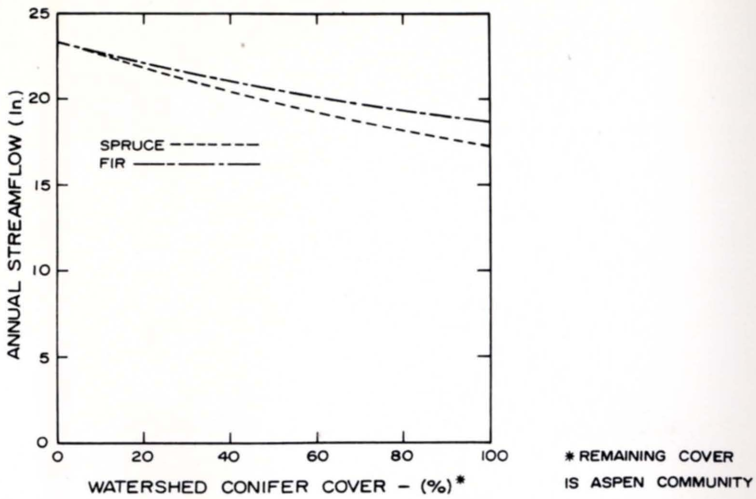

FIGURE 6. Streamflow reduction for the Chicken Creek watershed as a function of replacement of aspen forests by spruce and fir.

TABLE 2. Water budget components for an average water year on Chicken Creek Watershed at different stages of succession. All units are inches, except runoff, which is a percentage. (Multiply times 2.54 to obtain centimeters.)

Vegetation Status[1]	Streamflow	Streamflow[2] +Δ SM	Runoff[3]	QOF[4]	QF	Δ SM[2]	Δ GWL[2]	SEEP	TRAN	RINT	SINT	SVAP
0-100-0	23.3	22.9	48.7	5.2	15.8	-0.4	1.8	6.9	9.7	1.4	0.4	1.2
20-80-0	21.8	21.0	44.7	3.6	15.9	-0.8	1.8	6.9	11.0	1.6	0.8	1.1
40-60-0	20.4	19.2	40.9	2.2	15.9	-1.2	2.1	6.7	12.2	1.7	1.2	1.1
60-40-0	19.4	17.8	37.9	1.4	15.7	-1.6	2.3	6.4	13.2	1.9	1.6	1.0
80-20-0	18.4	16.4	34.9	0.5	15.6	-2.0	2.3	6.3	14.0	2.1	2.0	0.9
99-1-0	17.4	15.6	33.2	1.7	13.4	-1.8	1.7	5.5	15.5	2.3	2.4	0.9
0-80-20	22.1	22.0	46.8	3.7	16.1	-0.1	1.9	6.9	9.9	1.6	0.8	1.1
0-60-40	21.0	21.1	44.9	2.5	16.2	0.1	2.3	6.7	10.1	1.7	1.2	1.1
0-40-60	20.2	20.4	43.4	1.7	16.2	0.2	2.6	6.4	10.2	1.9	1.6	1.0
0-20-80	19.4	19.7	41.9	0.9	16.3	0.3	2.6	6.4	10.2	2.1	2.0	0.9
0-1-99	18.8	20.1	42.8	2.3	14.1	1.3	1.7	5.9	10.7	2.3	2.4	0.9
10-80-10	21.9	21.4	45.5	3.6	16.0	-0.5	1.9	6.9	10.5	1.6	0.8	1.1
20-60-80	20.7	20.1	42.8	2.4	16.1	-0.6	2.2	6.7	11.2	1.7	1.2	1.1
30-40-30	19.8	18.9	40.2	1.5	15.9	-0.9	2.4	6.4	11.8	1.9	1.6	1.0
40-20-40	18.9	17.8	37.9	0.6	16.0	-1.1	2.5	6.4	12.4	2.1	2.0	0.9
50-1-49	18.0	17.3	36.8	1.9	13.8	-0.7	1.9	5.6	13.6	2.3	2.4	0.9

[1]Percent watershed area cover composed of spruce, aspen, and fir communities, respectively.
[2] SM and GWL represent the net annual change in soil moisture and groundwater level, respectively.
[3]Runoff percent is equal to (streamflow + SM)precipitation) x 100.
[4]Alphabetical codes for annual hydrologic components.

- QOF - overland flow when soil is saturated
- QF - soil profile interflow
- SEEP - deep seepage
- TRAN - transpiration
- RINT - rainfall interception
- SINT - snowfall interception
- SVAP - snowpack evaporation

3. It was assumed in modeling that entire stands of a particular species would behave as did the 10-cm (4-inch) trees whose measurements were used to adjust the plant activity indexes and also for determining crop coefficients. Deviations as a function of tree size were not determined.

4. The actual number of hectares of aspen forest that could be managed to control successional patterns is not known. Therefore, sound estimates of potential water-yield impacts related to such management activities cannot be given.

Aspen-to-conifer succession reduces water yields

ABOUT THE AUTHORS

G. F. Gifford is professor of Rangeland Hydrology and chairman, Watershed Science Unit, College of Natural Resources. He has been a member of the faculty at USU since 1967 and his main interest is the impact on the hydrologic behavior of natural plant communities.

William Humphries and **Richard Jaynes** were graduate research assistants working on the project.

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